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PLAN FOR THE UNIFORM MAPPING OF EARTH RESOURCES AND

ENVIRONMENTAL COMPLEXES FROM SKYLAB IMAGERY

An Assessment of Natural Vegetation, Environmental,

and Crop Analogs

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December 1975
Final Report, Type III

Prepared for

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas 77058

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16. Abstract

A study was performed to develop and test a procedure for the uniform mapping and monitoring of natural ecosystems in the semi-arid and wooded regions of the Sierra-Lahontan and Colorado Plateau Test Regions, and for the estimating of rice crop production in the Northern Great Valley (California) and the Louisiana Coastal Plain. Skylab and high-flight and low-flight aerial photos were used in a visual photo interpretation scheme to identify vegetation complexes, map acreages, and evaluate crop vigor and stress. From these data an evaluation was made of the usefulness of various dates, scales, and spectral bands of coverage. A uniform hierarchical legend system was thoroughly tested. A series of photo interpretation tests and image feature measurements are reported.

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PREFACE

One of the most comprehensive photographic experiments ever conducted took place during the NASA Skylab satellite missions. At no previous time in history had such a carefully planned and executed photographic study been performed that extended over such a wide range of ground sites, covered a range of dates, incorporated systems that had been tried prior to the mission in extensive simulated earth orbital tests, utilized spectral bands that had been selected from years of exhaustive photographic research, and employed a vehicle and personnel that had been prepared and trained so completely for such an experiment. In addition, the support efforts that were organized to collect concurrent aerial photos and ground data were more comprehensive than ever before arranged.

For these reasons the data available for this study are without a doubt of the highest quality and are supported by more information on conditions of the ground scene and performance of the system than any previous photo study.

The data derived from the Skylab photographic study (Earth Resources Experiment Package, EREP) providing information of far-reaching significance in defining a system that eventually will photograph the Earth at scheduled intervals from orbital altitudes.

Another equally rewarding study was the NASA Earth Resources Technology Satellite (ERTS-1)* experiment using many of the same techniques

*ERTS has now been designated Landsat but the title ERTS is used throughout this report for consistency.

as the Skylab EREP study but from an unmanned satellite. That experiment was conducted over a longer period of time and obtained considerably greater volumes of data.

The present investigators have had the privilege of contributing to both the Skylab and ERTS experiments and this report is based on those studies. The contract under which this work was funded utilized Skylab data and supporting NASA aircraft photography and this report will address those data primarily. However, data from other sources including the ERTS-1 experiment will be utilized where those data sources will provide vital information not obtainable from Skylab photos.

The data obtained during both the Skylab and ERTS experiments will be most helpful in defining the satellite remote sensing systems of the future. That system will most probably utilize many of the components and techniques employed in those experimental systems in a combination of manned and unmanned satellites each providing a unique part of the operational Earth Observation Satellite (EOS) system.

The concepts and objectives of this investigation were the outgrowth of developmental earth resources research by the authors and their associates using simulated space photography, Gemini IV and Apollo VI and IX space photographs. These materials were used together with support aircraft photography in early experiments to inventory natural vegetation and estimate wheat and rice production. This new investigation was designed to contribute to the refinement of a scheme for the uniform mapping and monitoring of earth resources, environmental conditions, and important food crops through the interpretation of Skylab and support aircraft imagery. Central focus was on natural vegetation analogs and on rice as one of the world's most important food crops. Our hypothesis is that analogous

vegetations (natural and food crops) and environmental complexes should have sufficiently analogous remote sensing signatures that they could be recognized in each of many regions from subject/image relationships worked out in a few representative regions. The three natural vegetation objectives and three rice crop objectives may be paraphrased as follows:

> Further test and refine a uniform ecological legend for making natural resource inventories in two regions of the United States and identify the potentialities and limitations of the legend for Skylab interpretation.
>
> Determine the kinds of natural vegetation analogs that can and cannot be interpreted from the conventional photographic image products of the Skylab EREP system.
>
> Develop, test, and specify a practical procedure and system for uniform mapping and monitoring of natural ecosystems and environmental complexes by the use of space acquired imagery.
>
> Determine the dates of coverage, spatial and spectral resolution characteristics of Skylab EREP data and aerial support photos needed for rice crop identification.
>
> Determine the spatial and spectral resolution characteristics of Skylab EREP data and aerial support photos needed for evaluating plant stress and crop vigor conditions leading to yield estimation.
>
> Define the dates of coverage, the photo interpretation procedures and the data reduction methods needed to provide accurate rice yield estimates from Skylab and supporting aerial photography.

Our investigation was divided into two sections; one dealing with developing a uniform mapping legend and techniques for interpreting natural vegetation complexes and the other dealing with evaluating rice crop production in California and Louisiana.

The natural vegetation investigation will be discussed separately in the first part of this report followed by the findings of the rice crop investigation.

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1.0 NATURAL VEGETATION ANALOG INVESTIGATION

1.1 INTRODUCTION

The project discussed in this report had its origin with investigations that the authors and their associates conducted starting with Gemini IV and Apollo VI and IX experimental earth resources photography. During these investigations work was begun on a uniform system for the inventory and monitoring of vegetational resources and natural environmental complexes by appropriate combinations of space, aircraft imagery, and ground work. The research was continued through the ERTS-1 experiment and into Skylab for the purpose of further development and refinement of the uniform system for interregional application and to make comparative tests of three of the sensor systems aboard Skylab that were part of the Earth Resources Experiment Package (EREP).

Our working hypothesis has been that analogous vegetations and evnironmental complexes should have sufficiently analogous remote sensing signatures (at some appropriate level of classification) that they could be recognized widely throughout a region and, hopefully, in each of many regions from subject/image relationships worked out at a few representative locations. Given appropriate image quality control or radiometric fidelity, we have been able to accept this hypothesis as operationally feasible at various specified levels of classification in the hierarchical legend system we have been using to characterize the vegetation-landform systems that comprise the ecosystem units of the Earth's land mass. Other work by Earth Satellite Corporation (EarthSat) outside this project has also provided the opportunity to successfully apply the concepts on a global basis--on four continents.

Space technology now permits us to acquire both operationally

useable photography and multispectral scanner data from space--the former with very good spatial resolution and the latter with very good radiometric fidelity. Such imagery is appropriate to a broad spectrum of natural resources applications. It has given us the particular capability:

a. To image and analyze vast areas of the globe in a very short period of time,

b. To obtain very broad synoptic coverage and thus to transcend boundaries of agency and ownership responsibility and even of political jurisdiction,

c. To view both multidate and multispectral scenes simultaneously in reaching interpretive decisions about earth resources, and

d. To put earth resources and their use in a vivid, pictorial perspective provided that regional, national, or global systems of identification and annotation are developed and used.

Historically man has evaluated and planned the development, use, and management of earth resources; first from the highly restrictive view provided by ground observation, then from the substantially improved perspective of conventional aerial photography, and most recently from the still broader perspective obtainable from an earth-orbiting spacecraft. Also, historically speaking, the earth resources themselves have been managed quite restrictively by a multiplicity of government and private interests and, particularly, in the United States with each having its own local or restricted regional point of view. Consideration of resource problems in the context of small-to-major watersheds is about as close as we have traditionally come to development of a broad synoptic view of problems and

their interrelationships. In this context it has neither been necessary to develop a unified procedure for the identification of earth resource features across broader regions, nor a truly national or global legend for their identification and annotation. Each agency, landowner, or river basin commission could achieve its stated objectives by developing its own techniques and legend, largely independent of the views and need for coordination with others. After all, the project boundary seemingly was the true limit of concern.

When, on the other hand, we consider the ever-increasing dependence of one region or nation on another for food, fodder, fiber, and minerals and also for environmental protection, this limit of concern broadens commensurately. It is in this context that remote sensing from an earth-orbiting spacecraft assumes its greatest potential significance. The synoptic view offered from such a platform makes it possible for a single unified legend system and identification method to be applied across all ownerships throughout a vast area and then to draw together what each responsible agency knows into a common, integrated data base--much of which can be pictorially portrayed on a space-derived image or mosaic. It becomes even more appropriate in this setting to take an ecological approach to resource inventory and environmental monitoring when relating each kind of resource area to its land use potential and management requirements.

The specific objectives of the investigation now being reported are:

a. Further test and refine a uniform, hierarchical classification and legend system for the identification of natural vegetation and land surface characteristics from space and aircraft imagery,

b. Specify potentialities and limitations of the uniform legend concept for multistage, interregional, and potential global application and define the kinds of analogs that can and cannot be interpreted from the various types of space imagery,

c. Evaluate the contribution of stereo interpretation of space imagery to the accuracy of delineation and identification and for increasing the specificity of interpretable analogs,

d. Evaluate the effect of spatial resolution on interpretability, and

e. From comparative studies of stacked data over the same test sites, postulate an efficient multistage system for inventory and monitoring of natural ecosystems and man's impact upon them.

1.2 TEST REGIONS

To investigate problems implied by these objectives, we selected two widely separated test regions in the two major mountain chains of western North America (Figure 1)--the Colorado Plateau of southwestern Colorado and adjacent states and the Sierra-Lahontan of California and adjoining Nevada in the vicinity of Eastgate to Reno, Nevada and Lake Tahoe. The approximate local extent and shape of each test region is shown in Figure 2. Each of these test regions presents an analogous sequence of vegetational types from the salt desert to rocklands above timberline.

1.2.1 THE COLORADO PLATEAU TEST REGION

This test region includes vegetation zonation patterns highly similar to the Sierra-Lahontan with many vegetation analogs as well as a few vegetation types unique to its surrounding area (Figure 2). The zonation

Figure 1. Location of the two interregional test regions used in this study: Sierra-Lahontan and Colorado Plateau. (Also noted are two test regions used for a rice study performed as part of this investigation and reported in a later section of this report: Northern Great Valley and Louisiana Coastal Plain).

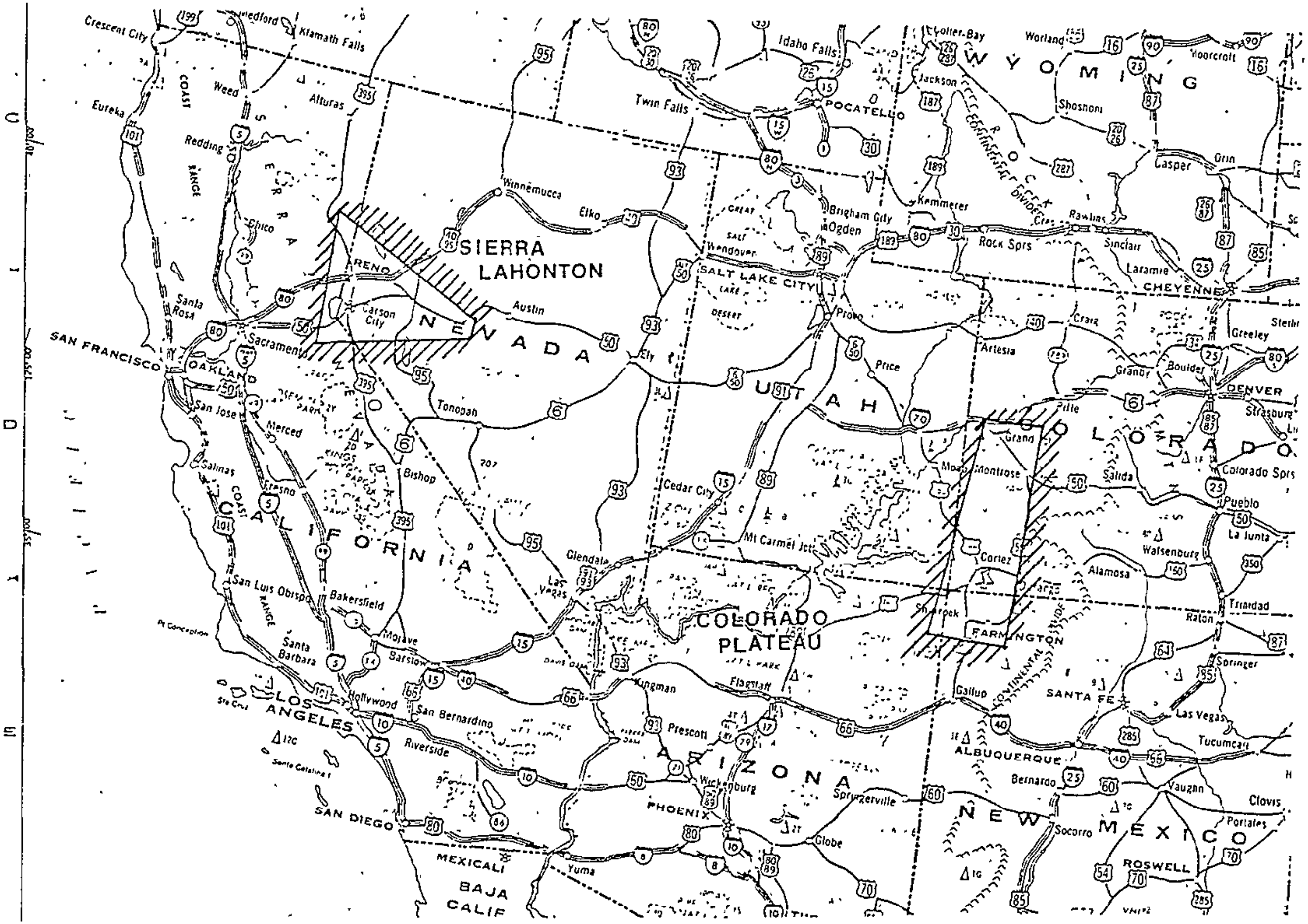


Figure 2. Approximate boundaries of the two natural vegetation test regions.

pattern within the Colorado Plateau Test Region is from the salt desert (Atriplex dominant) zone, through the sagebrush* or shrub steppe, pinyon-juniper, oakbrush, ponderosa pine, to aspen and spruce-fir, with some essentially alpine vegetation associated with the high mountain rocklands above timberline. A mixed coniferous type (Douglas-fir, true fir, and ponderosa pine) occurs in the area, but it is generally restricted to northerly aspects in the intermediate and upper elevations of the ponderosa pine zone. The spruce-fir zone is well-defined immediately below timberline. The two regions are contrasted particularly in the high preponderance of the deciduous Gambel oakbrush type of the Colorado Plateau with very limited distribution of sclerophyllous shrub types, such as manzanita.

The area has important geologic and mineral significance but in these respects is strongly contrasted to the Sierra-Lahontan. There are rather extensive areas of irrigated agriculture heavily oriented to livestock ranching. Forestry, mining, recreation, and wildlife are important in the region. This test area includes parts of two Indian reservations and large amounts of Bureau of Land Management and federal Forest Service land.

1.2.2 THE SIERRA-LAHONTAN TEST REGION

Direct analogs with the Colorado Plateau Test Region occur here. They are found in the salt desert zone, the sagebrush or shrub zone, the pinyon-juniper zone, and also in the Jeffrey pine zone, which is analogous with the ponderosa pine zone of the Colorado Plateau. In the Sierra-Lahontan Test Region, the spruce-fir zone is not distinctive as in southwestern Colorado. The spruce-fir of the latter test region is ecologically but not floristically analogous to the mountain hemlock types below timberline in the

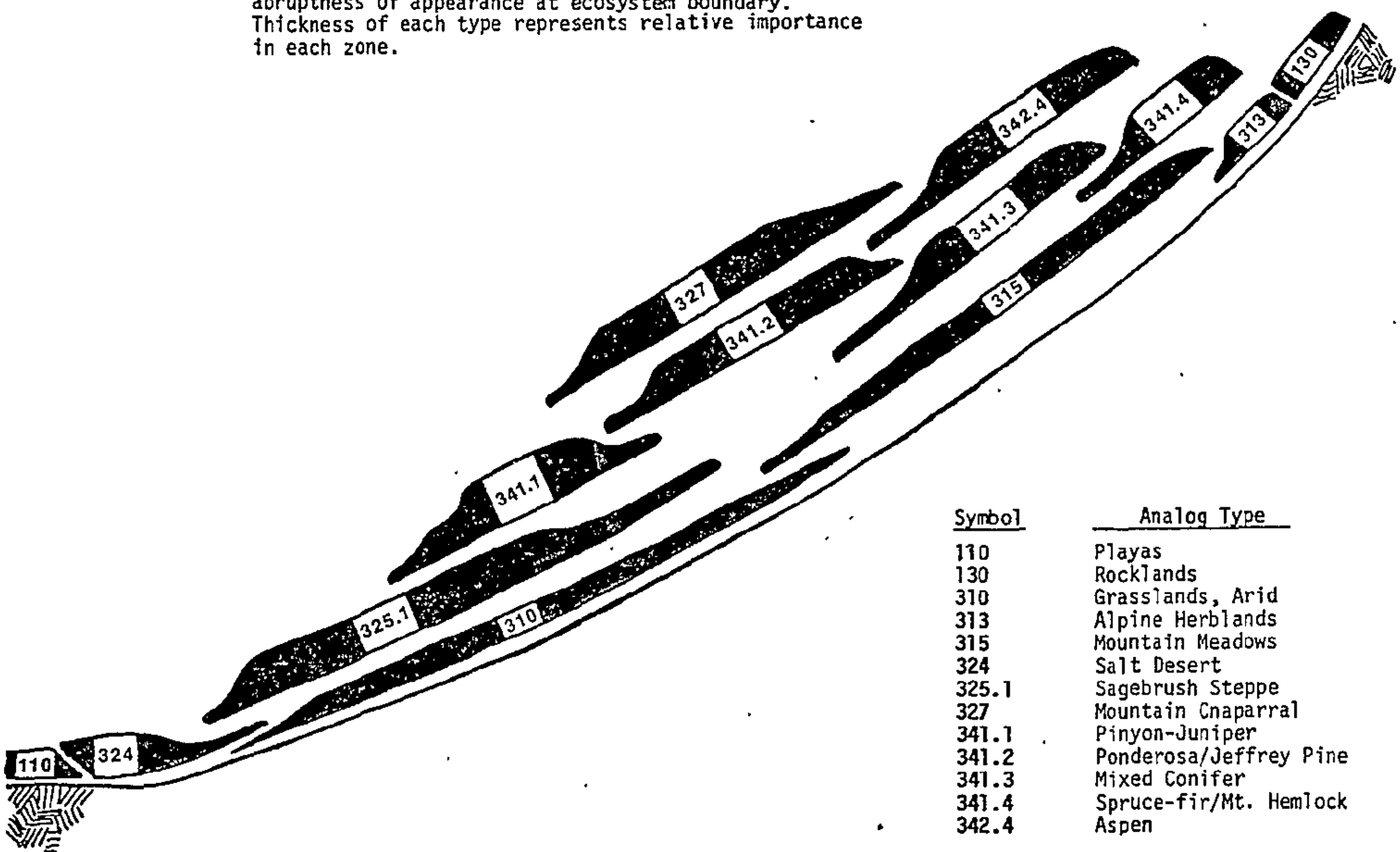
*For scientific names of important species see Appendix A (Table A1).

Sierra-Lahontan Test Region. One might expect the signatures of these two types, however, to be similar. In the latter area, the sclerophyllous shrub type predominates in most of the forest openings, and Gambel oakbrush is entirely absent. Deciduous oak trees are, however, present in the Jeffrey pine zone. This is in floristic contrast with the common occurrence of Gambel oak in the understory of ponderosa pine forests in the Colorado Plateau Test Region. In spite of the floristic contrast, these two types are ecologically analogous and one might expect their signatures to be similar in the two regions. The mixed conifer type (more extensive in this region) is essentially analogous with the north-aspect, mixed conifer types of the Colorado Plateau. An idealized picture of the vegetational zonation pattern in the two regions is shown in Figure 3.

There is an Indian reservation in the Sierra-Lahontan Test Region with similar preponderance of other federal land. The patterns of agricultural and crop types are highly similar with livestock production being a significant part of the local economy. Wildlife and recreation are also very important in this region. Aspen types occur but are much more restricted than in Colorado. The two regions are strongly contrasting geologically but, in spite of this good vegetational analogs do occur.

1.3 IMAGE AVAILABILITY

For the quantitative work under this project we settled on relatively small areas near Cortez, Colorado and Pyramid Lake, Nevada where, in spite of the interminable problems of clouds, mission scheduling and performance, and high-flight support acquisition, we did in fact have useable examples of all image types available superimposed over an identical area in each region. The available imagery that we were able to use in the experiments (exclusive of the high-flight that was used primarily for



Symbol	Analog Type
110	Playas
130	Rocklands
310	Grasslands, Arid
313	Alpine Herblands
315	Mountain Meadows
324	Salt Desert
325.1	Sagebrush Steppe
327	Mountain Cnaparral
341.1	Pinyon-Juniper
341.2	Ponderosa/Jeffrey Pine
341.3	Mixed Conifer
341.4	Spruce-fir/Mt. Hemlock
342.4	Aspen

Figure 3. Zonation pattern in two test regions. The low end of this idealized ecological gradient represents dry, hot, saline conditions. The high end represents contrasting moist, cool, slightly acidic conditions and relatively high altitudes.

ground truth confirmation on identifications and experimental mapping) is summarized in Table 1. The only serious problem arose when choices were made in favor of the all-important data superimposition (stacking) requirement. Interregional variation in photographic quality for the S-190A and S-190B systems as well as the high-flight photography made direct experimental testing of interregional interpretability with the photographic data impossible. In addition, a large part of the Sierra-Lahontan imagery lay outside our area of maximum ground truth although it had been covered by overflight aircraft observations in some detail and by two limited ground truth missions. Considering this problem, all of our experimental mapping was limited to the Colorado Plateau Test Region where the data stack also covered an area of high ground truth density. Formal photo interpretation tests were possible in both regions as individual experiments.

1.4 A PRACTICAL SETTING FOR EVALUATION

As we approach the question of the extent to which and how remote sensing imagery from space can be incorporated into the practical solution of natural ecosystem problems, it is important to note the relationships between scale and resolution in the resource use and management decision process. Each problem and level of administrative-management has its own general scale requirements for decision making. When we say resolution in this case, we mean both spatial and spectral, because there is a strong trade-off between the two which usually, in the practical context, has to be compromised. We can rarely have the best of both worlds, since for some solutions spatial resolution holds the key; while in other cases spectral resolution makes the greater contribution. The question can be disposed of by saying that it would be the grossest error to place emphasis only on one or the other.

Table 1. Types and Dates of Imagery Used in the Two Test Regions

System/Film	Date	Area
ERTS-1 CIR	May 18, 1973	Colorado Plateau
S-190A/CIR	June 5, 1973	Colorado Plateau
S-190A/Color	June 5, 1973	Colorado Plateau
S-190B/Color	June 5, 1973	Colorado Plateau
S-192 (1,7,9) Color	Aug. 4, 1973	Colorado Plateau
ERTS-1 CIR	July 25, 1973	Sierra-Lahontan
S-190A/CIR	Aug. 11, 1973	Sierra-Lahontan
S-190A/Color	Aug. 11, 1973	Sierra-Lahontan
S-190B/Color	Aug. 11, 1973	Sierra-Lahontan
S-192 (1,7,9) Color	July 25, 1973	Sierra-Lahontan

What one can derive from remotely sensed data is strongly and directly dependent upon the practical problem to be solved. There are levels of problems just as there are levels of scale and refinements in resolution. (See Figure 4.) In the complete management context, scales of 1:250,000 and smaller are superior for many problems in policy and broad planning. On the other extreme in practical resource management, especially in rangeland resources and forestry, sample point imagery at scales as large as 1:1,000 to 1:600, are often required if the contribution of remote sensing to efficient management is to be maximized.

Thus, we are addressing the question, "What is the role of space and high-flight imagery in this total process?" We are not at all concerned with the question, "Can or will space and high-flight imagery from presently available systems replace conventional aerial photography." The most effective operational system is a combined one. For specific problems it may or may not require a space component.

1.5 METHODS

1.5.1 GROUND TRUTH ACTIVITIES

Ground truth consisted of:

a. Vegetational and soil resource maps provided by cooperating federal agencies in the respective regions.

b. Ground observations made by EarthSat scientists at or near the time of overpass.

c. Supplemental notes and observations, particularly on vegetation phenology (seasonal development), by agency cooperators.

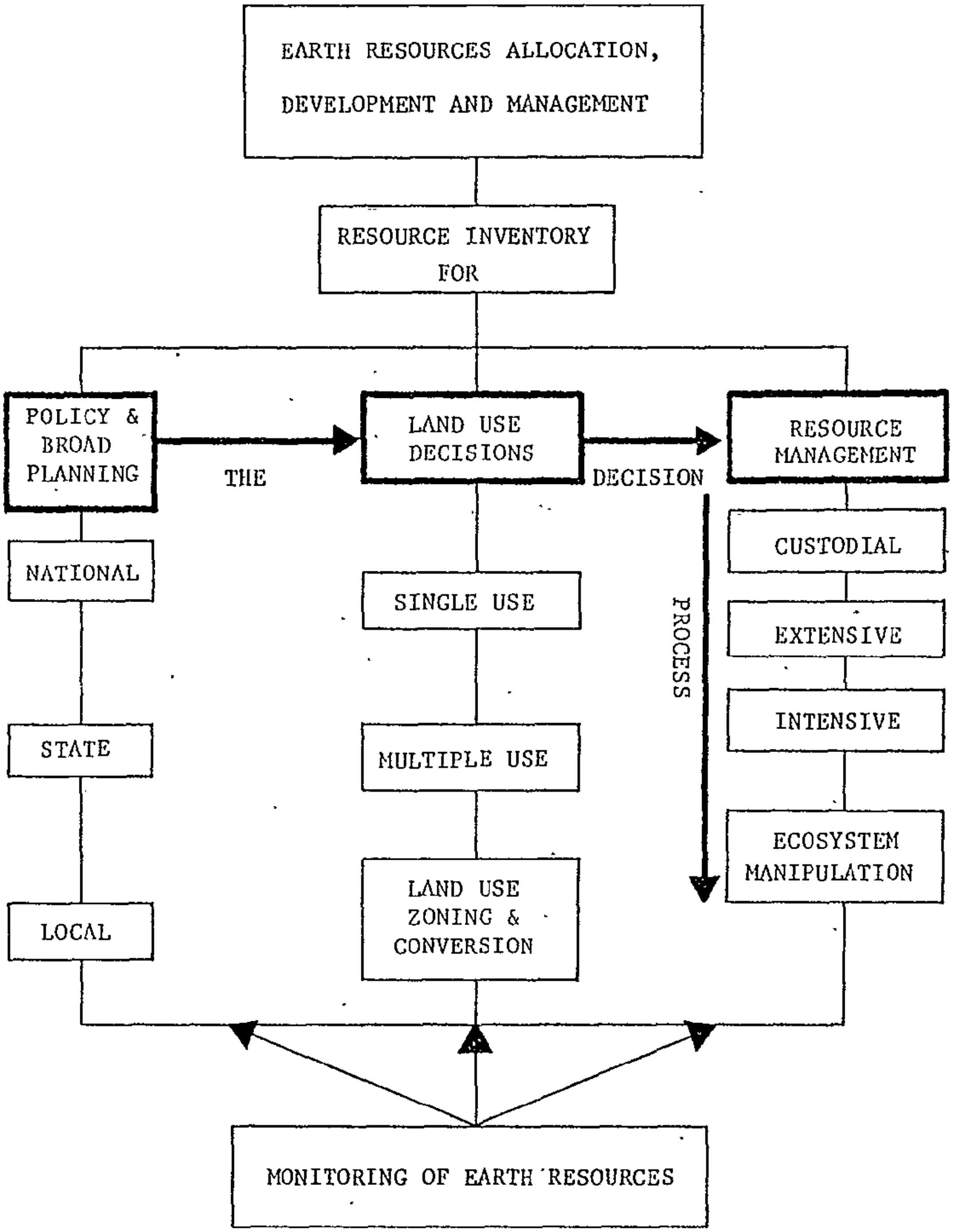


Figure 4. The decision process in resource allocation and management as it relates to level of problem, scale, and resolution.

d. Low-level aerial photography, vertical and oblique, flown by EarthSat staff at or near the time of key seasonal overpasses by Skylab;

e. High-flight photography provided by NASA.

The legend categories to fourth and fifth level were used directly for field and aircheck documentation. All of our ground truth data were plotted on 1:250,000 topographic sheets by numbered keys to facilitate relating them to each of the space images (Figure 5). Each of these locations was then transferred to an ERTS-1 1:250,000 enlargement with each datum point identified by legend symbol. Most of our critical mapping and interpretation experiments were done on 1:250,000 enlargements of the space image, although some work was done on the duplicate 9x9 transparencies provided by NASA.

1.5.2 IMAGE INTERPRETATION TESTING

Three separate interpretation tests were run using students from the remote sensing classes at the University of California, Berkeley. Groups of interpreters were selected on the basis of performance in the first-year course. None had had significant prior experience in photo interpretation. For each of the tests, ten students were assigned to two major groups consisting of five interpreters each. In the first test these groups evaluated the imagery by making a total set of 2,400 decisions on each of eight image types. The image types evaluated were from the Colorado Plateau only and consisted of the eight types shown in Table 2. In the first test, imagery at the approximate scale of 1:110,000 was used. In the second test, similarly constituted but different groups of interpreters evaluated imagery from both regions with all images enlarged to the common scale of 1:250,000. In this

Figure 5. All ground truth observations were located as they were acquired on 1:250,000 scale topographic maps. Support aerial photography missions were also charted on the same maps as indicated by the SW-NE trending black line in this illustration. Locations of key examples of each analog were then transferred to 1:250,000 scale ERTS color enlargements for use in interpretation testing experiments. Maps such as these are essential to the accessing of the ground truth record once it has been obtained and filed. The ideal way to match ground truth with the ERTS enlargement is by use of a mylar print of the 1:250,000 planimetric and topographic detail.

Table 2. The Image Types Evaluated in the First and Second Series of Interpretation Tests

First Test	Second Test
ERTS-1 Color Composite Band 5 B/W Band 7 B/W	ERTS-1 Color Composite
SKYLAB, S-190A Color Infrared Color Red Band B/W Infrared Band B/W	SKYLAB S-190A Color Infrared Color
SKYLAB S-190B Color	SKYLAB S-190B Color
	SKYLAB S-192 Color Composite

test five examples of each tester analog were evaluated for each image type (Table 2) to give a total of 250 decisions per image type in the two regions combined. (See Appendix B.)

In both of these tests training examples of each tester analog were identified on the imagery. Remaining examples were located and randomly numbered. The interpreters were given five minutes to study the training sets on each image type and 30 seconds each to identify each member of the numbered test set. These data were analyzed by Tukey's method of pairwise comparison and by the conventional commission-omission error analysis. In a third image interpretability experiment with the first of the above interpreters, ten individuals repeated the test by the interpretation of ERTS-1 in side-lap stereo. Subjective evaluations of interpretability were also made by highly experienced interpreters.

1.5.3 MAPPING EXPERIMENTS

All mapping experiments were performed on 1:250,000 enlargments of the color imagery. In addition, the full 13 seconds of S-192 color composited data were mapped at the scale of the imagery as provided by NASA in five-inch film format (approximately 1:737,000).

A set of mapping criteria and guidelines were prepared (Appendix C) and all imagery types were mapped according to these guidelines by a single interpreter to avoid variation in method since the primary purpose was to evaluate the various types of imagery. After doing the mapping in monocular examination, each area was additionally evaluated in stereo and notes were taken on the amount of line changes and number of identifications corrected as a result of the better perception of elevational and landform relationships.

As the mapping was done the interpreter assigned each boundary

delineation a "certainty of delineation" and an "identifiability" rating according to the criteria in Tables 3 and 4, respectively. These data were then summarized by image type and evaluated for indications of the superiority of image type.

These results were compared among image types as an assessment of possible benefits from the use of stereo from space and also to determine if there were differences among images types with and without the stereo contribution to the interpretation process.

The same test region was mapped and each analog identified from RC-8, color infrared high-flight photography. On this the legend units were positively identifiable and except for the problem of generalizing the mapping to somewhat correspond to the intensity used on the space imagery, type delineation was very accurate. These maps were then compared as regards the kinds and nature of analogous features within each mapping unit on the five kinds of space imagery evaluated in the second test (Table 2). As an additional check for the southern part of the test region, mapping was compared with vegetation and soils maps prepared by the Bureau of Indian Affairs and some Forest Service type maps provided spot-checks in other areas.

In addition, 16 relief conditions were identified and measured from 1:250,000 topographic sheets. These points were located on each image type and evaluated as to the clarity with which they could be perceived in stereo examination. These results were summarized to compare image types and to establish the relief thresholds discernible with each type of imagery. The stereoscopic comparison was made at both the 1:250,000 scale and the 9x9-inch NASA product duplicate scale of approximately 1:737,000. In all cases

Table 3. Criteria for Rating the Ease and Certainty of Delineating Boundaries

Rating	Possibility of Defining Boundary Delineations
1	Boundary line easy to decide, clear, and distinct.
2	Boundary delineation presents some problems, some area of diffuse boundary but mostly fits condition 1.
3	Boundary definition has some alternatives; specifically, half or more of boundary shows diffuse change, thus allowing for different interpretations of where the boundary should fall. However, for any of these alternatives, differentiation definitely appears stronger after line is drawn. Line is not significantly arbitrary.
4	Boundary definition is quite arbitrary, likely to be made with marked difference by different people; only small portions of boundary (<30%) are distinct as in 1, 2, or 3.

Table 4. Criteria for Rating the Identifiability of Images

Rating	Possiblity of Image Identification
1	Positive; little likelihood of identification errors.
2	Reasonable certainty; probably a few inconsequential identification errors.
3	Moderate chance of error; identification highly dependent on associated convergence of evidence or local familiarity.
4	Substantial chance for error; attempted identification is little better than a guess.
5	Inadequate information to identify; no identification.

transparency materials were used--for interpretation testing and mapping experiments.

Finally, based on our accumulated experience the above evaluations and the operational use of space imagery in the EarthSat applications program, a flow diagram was developed for a suggested operational system to analyze landscapes by appropriate combinations or alternatives of space imagery and aircraft photography.

1.5.4 CLASSIFICATION AND LEGEND SYSTEM

Since Dr. Charles E. Poulton's first involvement with space imagery in 1966, he and his associates have been evolving an hierarchical legend system under a consistent set of discriminative criteria. The system is especially suited to multistage remote sensing application and is decimal numerical for computer compatibility.[1] This effort has stabilized into a format and set of classification categories that is published elsewhere and has enjoyed widespread practical application in comprehensive ecological analysis of earth resources and land use studies.[2,3]

[1] Poulton, Charles E., Barry J. Schrumpf, and Edmundo Garcia-Moya. 1971. A Preliminary Vegetational Resource Inventory and Symbolic Legend System for the Tucson-Willcox-Fort Huachuca Triangle of Arizona. In Colwell, Robert N. (ed.). Monitoring Earth Resources from Aircraft and Spacecraft. National Aeronautics and Space Administration. Sci. and Tech. Info. Office. Washington, D.C. NASA SP-275. pp. 93-115.

[2] Poulton, Charles E. 1972. A Comprehensive Remote Sensing Legend System for the Ecological Characterization and Annotation of Natural and Altered Landscapes. Proceed. Eighth International Symposium on Remote Sensing of Environment, 2-6 October 1972. Willow Run Laboratories, Environmental Research Institute of Michigan, Ann Arbor. pp. 393-408.

[3] Legge, Allan H., et al. 1974. Development and Application of an Ecologically Based Remote Sensing Legend System for the Kananaskis, Alberta, Remote Sensing Test Corridor (Subalpine Forest Region). International Society for Photogrammetry, Banff, Alberta, Canada. 7-11 October 1974.

From the standpoint of plant ecology, vegetation and soil resource management, a classification and characterization of the form of the land surface is extremely important to both the student of landscapes and resource ecology and to the resource manager. For many years in Dr. Poulton's research at Oregon State University and in projects involving his graduate students, they have used a three-component system for landscape characterization. The components are: macrorelief, landform, and microrelief.

Macrorelief refers to the largest categories of classification of major relief change within the landscape system being described. Landform refers to the specific form of the landscape as a secondary level characterization. The classes we have devised to date are consistent with and accommodate the major landform features recognized by geomorphologists within the two broad categories of fluvial and desert erosional characteristics or provinces. They also accommodate equally well the concept of features of negative and positive relief, i.e., high features and depressional features.

After trying repeatedly to use the technical landform classifications of the geomorphologists, we have gone back to a set of classes, with some modification and improvement, similar to the ones Dr. Poulton started to use in the early 1950s while conducting vegetation-soil relationships studies in forested and rangeland environments. While these classes may cause the professional geomorphologist some pain, they do have the distinct advantage of being especially relevant to and capable of depicting the kinds of landform features that are most relevant to plant ecology and soil development and to the practical use, development, and management of earth resources.

The microrelief classes define the contour of local landscapes, features of very low relief. For example, they express the micro-contour

of a single mountain slope, small undissected mesa, or valley bottom.

Most of the classes or categories have been previously described and illustrated in various NASA reports and other publications where they do not make use of common terms described in the geomorphological literature. In the interest of time and space, descriptions of the classes are not included herewith. It is sufficient for the purposes of this report merely to indicate the format of the system (Figure 6). The legend for all analogs evaluated in this project and for the characterization of the land surface is presented in Appendix A. The one new development that came out of this project was an improvement and refinement in the macrorelief and landform classes over that presented in 1972 (Poulton, 1972). The major change involved bringing all classes under the same decimal numeric system and revising the landform classes to more logically accommodate the land surface features that are ecologically significant in vegetation and soil development and in land use and resource management decisions (Figure 7).

1.6 RESULTS AND DISCUSSION

1.6.1 QUANTITIATIVE COMPARISON OF IMAGE TYPES FOR INTERPRETABILITY

The purpose of these quantitative tests was to determine which of five image types were superior for ocular identification of natural vegetation analogs in the two test regions. The analogs used in the test are shown in Table 5. An "Other Vegetation Types" class was included so that a variety of unknown image types could be interjected into the testing to create possible confusion with the subject analogs and thus provide a better assessment of true interpretability.

In conducting the test, the students were given a brief discussion

Vegetation Analog or Land Use Condition

Land Surface Characteristics

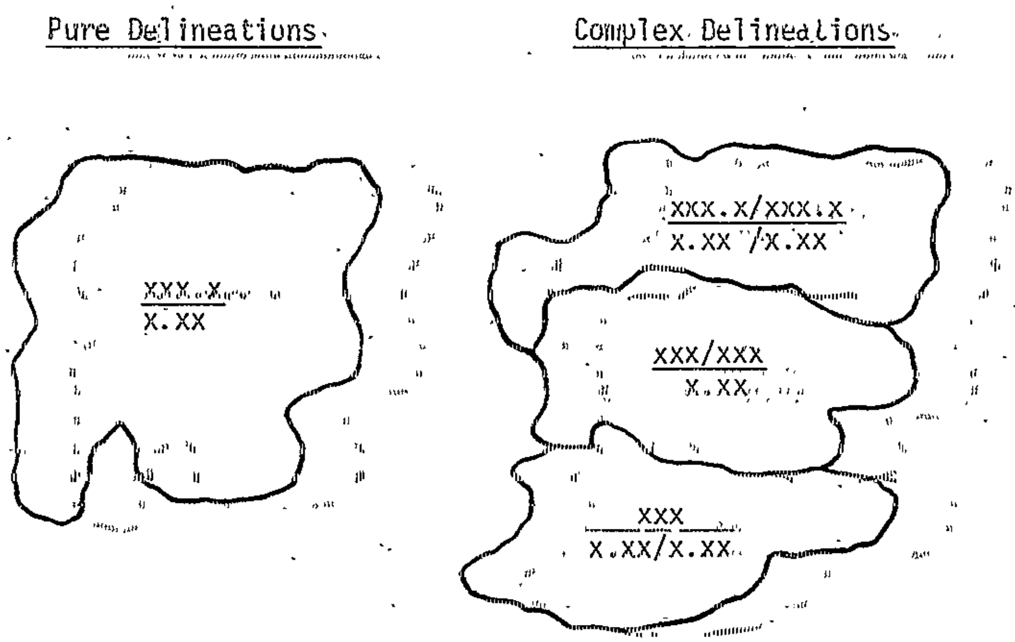
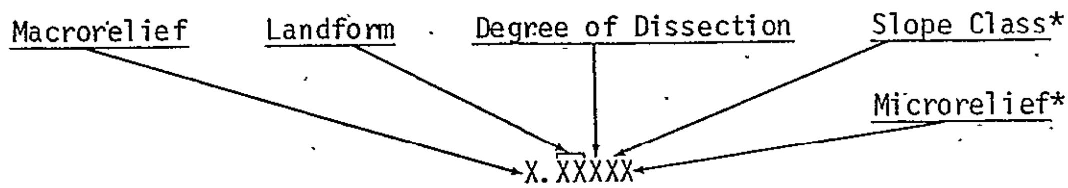


Figure 6. The symbolic legend format for use in delineation identification or in entry into a computerized data base.



*These two levels are generally appropriate to use only with intensive large-scale inventories at scale of about 1:25,000 and larger.

Figure 7. Symbolic legend format for annotation and description of land surface characteristics.

Table 5. Analogs Used in Interpretation Tests One and Two

Numeric Symbol	Vegetation Type	Alpha Symbol	Used in Test	
			One	Two
315	Meadows	W	√	
325.1	Sagebrush	Sa		√
341.2	Ponderosa/Jeffrey Pine Forest	P	√	√
341.1	Pinyon-juniper Woodland	J	√	√
341.4	Spruce-fir	S	√	
342.4	Aspen	A	√	
347	Oakbrush/Mountain Chaparral	B		√
	Other Vegetation Types	X	√	√

of the common vegetational zonation patterns in the two regions and the various analog types were described so they would have some feeling of familiarity with the subject areas. In the familiarization discussion no mention was made of image characteristics associated with the vegetation analogs.

The image set for the Colorado Plateau Test Region represented green season phenological development in the lower and middle altitudes, and pre-emergence dormant season at the very highest altitudes. The full-development, green condition prevailed generally below 9,000 feet elevation and pre-emergence dormant season essentially above 9,000 feet, except for evergreen species. The Sierra-Lahontan Test Region represented the dormant season condition below approximately 6,000 to 7,000 feet, and green mature vegetation conditions above approximately 7,000 feet. These particular dates in each of the two regions were selected because they were the only dates on which we accumulated useable, essentially cloud-free imagery for all image types over the same area. A much more desirable test would have been achieved had it been possible to use both green and dry season imagery for both of the analogous regions.

1.6.1.1 INTERPRETATION TEST ONE

Statistical Analysis: On the basis of Tukey's method of pairwise comparison, the image types compared in Test One can be ranked in order as shown in Table 6. From this table it is seen that the two best image types are S-190A color infrared and ERTS-1 color composite. S-190B color ranks third, thus its higher resolution on color film did not compensate for the color infrared spectral qualities. It is interesting to note that black-and-white infrared imagery ranked close alongside S-190B color in this test with the suggestion that both black-and-white types (ERTS-1 and S-190A) may be more accurately interpretable for the point identification of vegetation analogs than S-190A color. The red band imagery was poorest of all.

Table 6. Ranking of Images in Decreasing Order of Interpretability

Image Type	Overall Average Correct Responses (All crop categories)[1/]
EREP S-190A Color IR	7.9
ERTS-1 Color Composite	7.0
EREP S-190B Color	6.4
EREP S-190A B/W IR	6.4
ERTS-1 Band 7	6.2
EREP S-190A Color	5.5
EREP S-190A B/W Red	5.2
ERTS-1 Band 5	4.6

[1/] Maximum possible value = 10. Test is by Tukey's method of pairwise comparison.

It is informative to consider the image types that resulted in the fewest commission errors for each vegetation analog in this more comprehensive single-region test. These results are presented in Table 7.

The importance of high resolution in the S-190B color is evident in its superiority for identification of the sedge meadow analog. Sedge meadows are narrow stringer types in this region. They rarely occur except in narrow valley bottoms and around the edge of small lakes. Such features can only be seen and correctly interpreted on S-190B.

With the general inferiority of black-and-white broad band imagery for visual interpretation one might wonder why S-190A black-and-white infrared was among the best image types for aspen, spruce-fir, and "other natural vegetation" categories. With the test imagery taken in the summer green season, aspen would be very highly reflective, thus producing unusually light tones in sharp contrast to the spruce-fir which occurs largely in juxtaposition with aspen and would image as a very dark tone on black-and-white infrared. Thus, whenever the sharp edge of black on white was observed on S-190A black-and-white infrared at high elevations, the logical conclusion would be to identify aspen for the light tones and spruce-fir for the dark tones.

The "other natural vegetation" category was probably interpreted well on S-190B color because we tended to select small contrasting vegetation analogs for the "others" category. It is important also to note that color infrared was superior for five vegetation analogs, whereas color was superior only for three analogs. One should recognize, however, that in one instance (S-190B) the opportunity did not exist to compare both color and color infrared from this high resolution system. It is quite likely that the CIR would also have been superior over color film in the S-190B system.

Table 7. Analysis of Test Data

(Natural Vegetation Identification Test)
Ranking of Image Types by Commission Error

For each of the natural vegetation categories listed below, the image type(s) are given which form a group that is significantly different from all others in terms of commission error (using Tukey's method of pairwise comparison). These images are those for which commission errors are lowest.

Natural Vegetation Category	Image Type
Pinyon-juniper	EREP S-190A Color IR
Ponderosa pine	EREP S-190A Color IR
Sedge meadow	EREP S-190B Color
Aspen	EREP S-190A Color IR EREP S-190A Color EREP S-190A B/W IR
Spruce-fir	EREP S-190A Color IR EREP S-190A B/W IR ERTS Color Composite
Other natural vegetation	EREP S-190A Color IR EREP S-190A B/W IR EREP S-190B Color

In summary, these results indicate the general superiority of color infrared remote sensing products for all natural vegetation interpretations.

Commission-omission error analysis: The results of the more comprehensive Test One are also summarized from a conventional commission-omission error analysis in Table 8. If one looks first at the percent correct for the eight image types, it is apparent that both ERTS-1 color reconstitution and S-190A CIR meet frequently acceptable standards of accuracy, particularly the latter. ERTS-1 black-and-white Band 7, S-190A black-and-white infrared, and S-190B color gave essentially the same results; and next to the color infrared renditions, S-190A color and S-190A black-and-white red band were poorest in terms of point identification accuracy.

If one looks at the percent commission error category, comparisons can be made more explicitly (Table 9). This difference matrix shows ERTS-1 4, 5, 7 color reconstitution superior to three out of seven other image types. It was better than ERTS-1, Band 5, and S-190A color and black-and-white red band. S-190A color infrared was not different but with a nonsignificant suggestion that it might hold a slight edge over ERTS-1 4, 5, 7 reconstitutions. However, this hypothesized advantage would be overriden by the image quality control problems (poor radiometric fidelity) of the S-190A camera system. In our experiment the planned interregional comparisons were impossible because of this problem.

The S-190A color infrared was superior to ERTS-1 Band 7 only at a low probability (P=0.90); but it was highly superior to S-190A color. The S-190B color was superior to S-190A color (P=0.95) but also inferior to S-190A color infrared (P=0.90). In all comparisons the black-and-white red or Band 5 was outstandingly poor, with commission errors of 48.7 and 53.5 percent.

Table 8. Comparative Interpretation Errors by Image-Type From Test One (2400 Decisions)

Image Type	Percent Correct	Percent Commission Errors	
		Range in %	$\bar{x} \pm SE_{\bar{x}}$
ERTS-1 Color	71	11-43	30.33 ± 5.02
ERTS-1 Band 7	62	16-58	37.33 ± 6.81
ERTS-1 Band 5	46	44-67	53.50 ± 3.50
S-190A CIR	78	10-26	21.51 ± 2.81
S-190A Color	55	35-50	44.7 ± 2.11
S-190A B/W IR	64	12-56	35.8 ± 7.01
S-190A B/W Red	52	42-57	48.7 ± 2.67
S-190B Color	65	18-46	33.3 ± 4.59

Table 9. Significance of Difference Matrix Comparing Image Types from Test One

Image Type	ERTS-1 Color	ERTS-1 B-7	ERTS-1 B-5	S-190A CIR	S-190A Color	S-190A B/W IR	S-190A B/W Red	S-190B Color
ERTS-1 Color	X							
ERTS-1 B-7	7.06	X						
ERTS-1 B-5	** 13.17	+ 16.17	X					
S-190A CIR	8.83	+ 15.83	*** 32.00	X				
S-190A Color	* 14.37	7.37	+ 8.80	*** 23.20	X			
S-190A B/W IR	5.47	1.53	* 17.70	+ 14.30	8.90	X		
S-190A B/W Red	** 18.37	11.37	4.80	*** 27.20	4.00	12.90	X	
S-190B Color	2.97	4.03	*** 20.20	+ 11.80	* 11.40	2.50	$\underline{*}$ 15.40	X

LEGEND: *** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

1.6.1.2 INTERPRETATION TEST TWO

Statistical Analysis: Based on experiments performed under this contract in only the Colorado Plateau region during the spring of 1974, we decided that substantially fewer than 2,400 interpretation decisions would provide acceptable results.[1] Both cost factors of employing experimental interpreters and especially the time required to process larger amounts of data led us to compromise on five interpreters and four tester analogs on the five image types in two regions for these additional comparisons of ERTS-1 and Skylab data.

The basic data derived from Test Two are displayed in Table 10. These data were first analyzed by a one-way analysis of variance which showed highly significant differences in the Group I Sierra-Lahontan data and significant differences in Group II Sierra-Lahontan data. The accuracy obtainable with the image types in the Colorado Plateau region were not significantly different, although Group II approached significance. Careful study revealed that there was a tendency for variation among interpreters and in image quality to obscure meaningful differences when all the data were grouped. Using between-region differences in correct identifications with a given image type as an index of regional variation in image quality, or the effect of seasonal difference between regions, the interpretability of ERTS-1 data was different between the two regions at a probability far in excess of 0.99. Similarly, Group II interpreted both S-190A color and S-190B color imagery differently between the two regions at a probability far in excess of 0.99.

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[1] Results published in a special technical report to NASA, "A Comparison of Skylab and ERTS Data for Agricultural Crop and Natural Vegetation Interpretation." By Earth Satellite Corporation. July 1, 1974.

Table 10. Percent Correct Interpretation by Ten Interpreters for Five Image Types in Two Regions

Group	Interpreter	Colorado Plateau 192	Colorado Plateau 190B COLR	Colorado Plateau 190A COLR	Colorado Plateau 190A CIR	Colorado Plateau ERTS-1		Sierra-Lahontan 192	Sierra-Lahontan 190B COLR	Sierra-Lahontan 190A COLR	Sierra-Lahontan 190A CIR	Sierra-Lahontan ERTS-1
1	H	79	80	92	84	76		48	52	56	64	92
	M	63	76	68	68	60		56	68	84	84	92
	O	67	52	48	60	44		56	76	60	80	88
	S	58	76	72	60	56		60	68	60	72	80
	V	67	84	84	84	60		60	64	60	80	92
	$\bar{X}$	66.8	73.6	72.8	71.2	59.2	$\bar{X}$	56.0	65.6	64.0	76.0	88.8
	$SE_{\bar{X}}$	3.47	5.60	7.53	5.43	5.12	$SE_{\bar{X}}$	2.19	3.92	5.06	3.58	2.33
2	C	54	80	88	76	68		68	52	64	68	68
	Ho	79	72	80	80	48		76	72	64	80	92
	L	67	88	76	80	80		60	56	60	76	100
	P	63	84	68	56	60		64	64	60	72	88
	Vo	79	72	72	72	64		64	52	48	72	80
	$\bar{X}$	68.4	79.2	76.8	72.8	64.0	$\bar{X}$	66.4	59.2	59.2	73.6	85.6
	$SE_{\bar{X}}$	4.81	3.20	3.44	4.45	5.22	$SE_{\bar{X}}$	2.71	3.88	2.94	2.04	5.46
GRAND	$\bar{\bar{X}}$	67.6	76.4	74.8	72.0	61.6		61.2	62.4	61.6	74.8	87.2
	$S_{\bar{\bar{X}}}$	2.81	3.18	3.96	3.32	3.54		2.39	2.81	2.87	1.98	2.85

Only S-190A CIR imagery was interpreted with the same accuracy by both groups in both regions.

The results for Group I and II in the Sierra-Lahontan region and the combined groups for the Colorado Plateau region were then tested for significant differences among all image type comparisons. These data are summarized in matrix Tables 11, 12, and 13. This analysis shows that, at varying levels of probability (all in excess of P=0.90) the interpretability of ERTS-1 data was higher than all other types in the Sierra-Lahontan. Also at varying levels of P=0.90, S-190A color infrared was superior to S-190A color, S-190B color, and S-192, except one instance of a group interaction in the test. Group II gave highly significant superiority to S-190A color infrared over S-190A color, but Group I did not show a difference between these two image types. No other comparisons gave significant results. This suggests that the radiometric qualities of color infrared are more important in contributing to accuracy of interpretation than is the high resolution of the S-190B system. The same can be said with respect to the ERTS-1 color infrared rendition, in spite of its lower resolution, as compared to both of the Skylab camera systems.

It is somewhat surprising that S-190B color did not rate higher in this test. A possible explanation is that, for point identification of image types (where mapping decisions are not involved) the higher resolution of both the S-190B and S-190A color is unimportant. It is likely that had we used color infrared film in the S-190B camera, its interpretability score would have been substantially higher (see section on mapping experiments where S-190B color and S-190A color were both found superior to ERTS-1 and S-190A color infrared imagery).

Table 11. Significance of Difference Matrix Comparing Image Types by Group I Interpreters in the Sierra-Lahontan Region

Image Type	192	190B Color	190A Color	190A CIR	ERTS-1
192	X				
190B Color	9.6	X			
190A Color	8.0	1.6	X		
190A CIR	** 20.0	+ 10.4	12.0	X	
ERTS-1	*** 32.8	** 23.2	** 24.8	$\underline{*}$ 12.8	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

Table 12. Significance of Difference Matrix Comparing Image Types by Group II Interpreters in the Sierra-Lahontan Region

Image Type	192	190B Color	190A Color	190A CIR	ERTS-1
192	X				
190B Color	7.2	X			
190A Color	7.2	0	X		
190A CIR	+ 7.2	$\underline{*}$ 14.4	** 14.4	X	
ERTS-1	$\underline{*}$ 19.2	** 26.4	** 26.4	+ 12.0	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

Table 13. Significance of Difference Matrix Comparing Image Types by Groups I and II Interpreters in the Colorado Plateau Region

Image Type	192	190B COLR	190A COLR	190A CIR	ERTS-1
192	X				
190B COLR	8.8+	X			
190A COLR	7.2	1.6	X		
190A CIR	4.4	4.4	2.8	X	
ERTS-1	6.0	14.8**	13.2**	10.4	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

In the Colorado Plateau area, ERTS-1 color reconstitution proved inferior to both S-190B color and S-190A color at a highly significant level. S-190B color was superior to S-192 at P=0.90. No other differences approached significance in the Colorado Plateau test. The reason for poor performance in the Colorado Plateau region may be the season of imagery used. For the low elevation arid types, it was peak green. Differentiations between sagebrush and salt desert were somewhat difficult and images were particularly variable because of soil type variation. At the intermediate elevations oakbrush was in full leaf and tended to override associated juniper and ponderosa pine when the latter were in open stands. At the high elevations, vegetation was still dormant so that poor discriminations were provided between aspen and meadow types and between oakbrush and aspen stands where the former fingered up into the higher elevations.

Commission-omission error analysis: A standard commission-omission error comparison was also performed on the Test Two data (Table 14). The Sierra-Lahontan study (those most consistently significant in comparisons among image types) gave essentially the same results as the more comprehensive Test One, insofar as color imagery is concerned.

From the Colorado Plateau Test Region, ERTS-1 data ranked poorest of all on the basis of "total percent correct" and interpretations and commission errors, although differences were small and few of them significant. The best results were obtained for this region with S-190B color, both on the basis of total correct and the number of commission errors; although in these instances we are talking about apparent differences, none of which would be found significant at reasonable probability levels. On the basis of commission errors, a suggested ranking of S-190B best and

Table 14. Comparative Interpretation Errors by Image Type From Two Regions, Test Two (1,250 Decisions)

Image Type	Percent Correct		Percent Commission Errors			
	Colorado Plateau	Sierra-Lahontan	Colorado Plateau		Sierra-Lahontan	
			Range	$\bar{x} \pm SE_{\bar{x}}$	Range	$\bar{x} \pm SE_{\bar{x}}$
ERTS-1 CIR	62	87	20-45	36.8 ± 4.06	0-21	12.7 ± 2.79
S-190A CIR	72	75	13-36	27.5 ± 2.26	6-34	24.4 ± 3.11
S-190A Color	75	62	16-40	28.9 ± 5.39	11-68	39.5 ± 5.61
S-190B Color	76	62	0-33	22.9 ± 3.13	13-49	37.2 ± 6.08
S-192, 1, 7, 9, Color	68	61	0-38	33.2 ± 8.43	28-52	37.4 ± 4.81

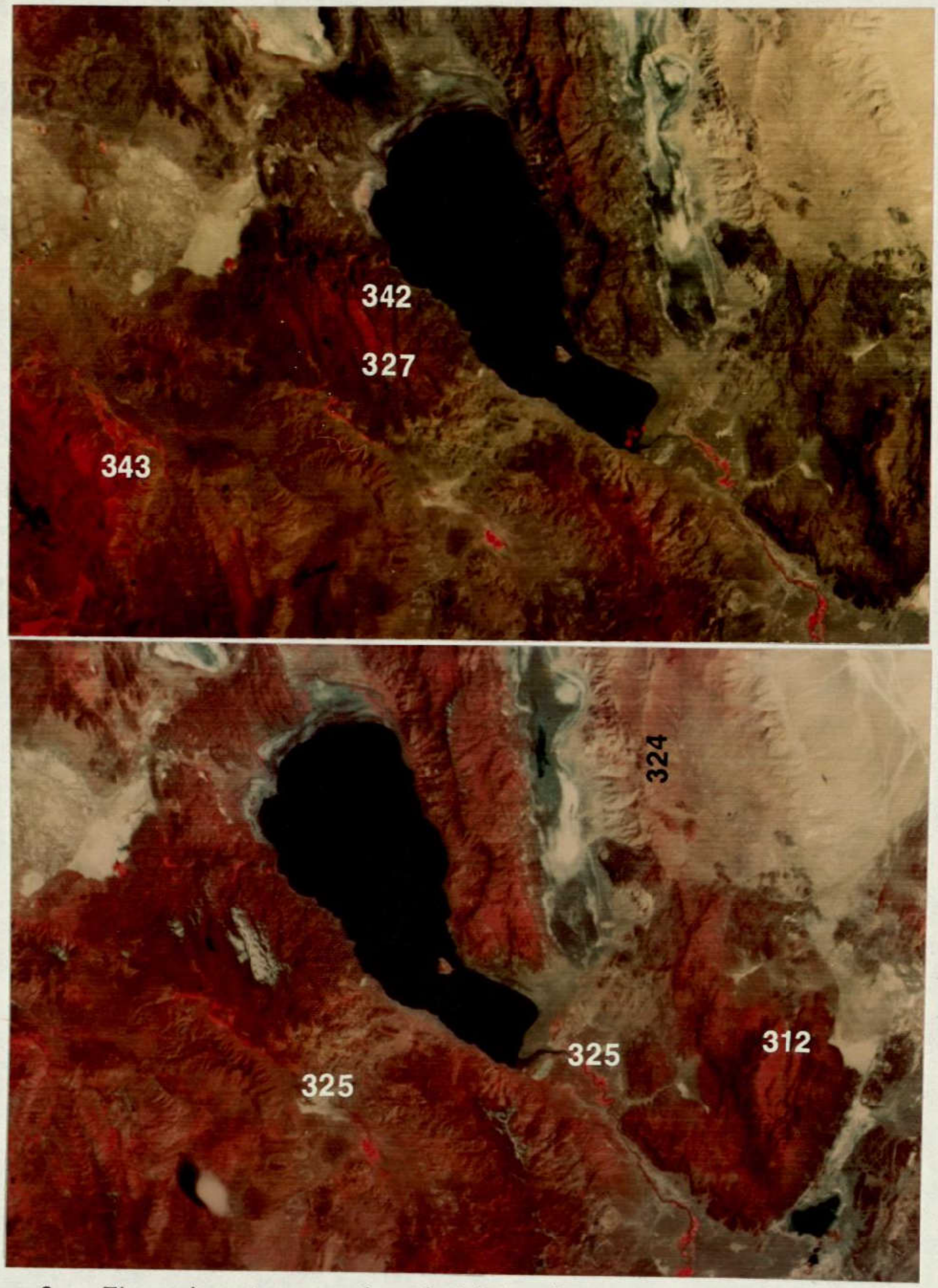
ERTS-1 with S-192 poorest is suggested by the Colorado Plateau data; and ERTS-1 best with S-190A color, S-190B color, and S-192 poorest in the Sierra-Lahontan region (Table 14).

If these data were combined for all groups and regions, the combined magnitude of error and compensating differences resulted in essential nonsignificance. Only S-190A color infrared and ERTS-1 color reconstitutions were significantly better than S-192 (P=0.99 and 0.95, respectively). A more specific explanation may be that some of the images, particularly ERTS-1, were far superior for the Sierra-Lahontan than for the Colorado Plateau. In the Colorado Plateau, the ERTS-1 image was uniformly red to pink for many vegetation types, whereas they were strongly contrasting in Sierra-Lahontan. The same can be said of the S-190A color infrared, although the problem was not as bad as with ERTS-1 data in the Colorado Plateau.

These results further support a practical guideline that our accumulated experience has suggested--namely, the best seasons for imaging natural vegetation with color infrared is as the vegetation types of interest are moving into the dry or mature season. The interpretability of many types of natural vegetation is nearly always low during the peak green season.

In making these statements one must not minimize the importance of the multidate imaging capability of the ERTS-1 system. Both for full visual and machine aided interactive interpretation of space imagery, the multidate component is the only way some identifications can be made with reliability (Figures 8 and 9).

The most specific statement that can be made from this series of comparison is that ERTS-1 and S-190A color infrared are the superior image types when the capability of interpreters to correctly identify point images is the criterion for judgment, and that ERTS-1 over S-190A color infrared seems



1002-18125
July 25, 1972

1290-18115
May 9, 1973

Figure 8. The advantages of multidate imagery for the evaluation of natural vegetation of both range and forest lands must not be discounted. This scene shows how spring vs. late summer imagery can be combined, in the first instance to differentiate lower elevation grasslands (312), sagebrush steppe (325), and even the more productive phases of the salt desert (324). The latter differentiations are very difficult or impossible in late summer imagery. Similarly late spring imagery does not differentiate the mountain brush chaparral (327), aspen (342), and the mixed pine-oak (343) types but mid- to late-summer imagery (top example) does an excellent job of this discrimination. ERTS-1 photos.

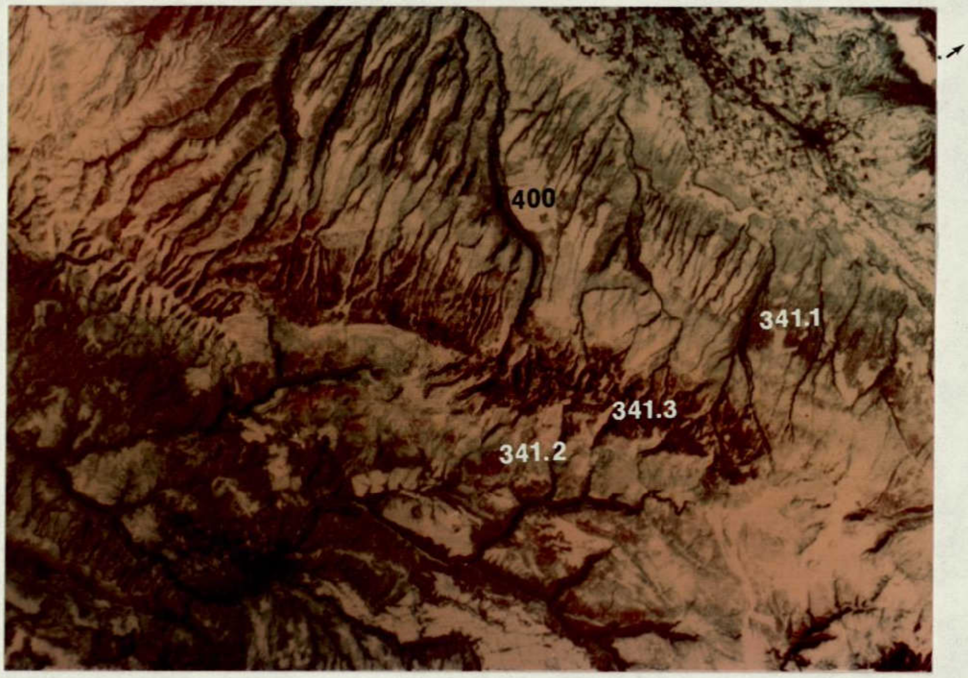


Image ID: 1210-17262
February 18, 1973
ERTS-1

Figure 9. A snow background increases the contrast among many features of importance. The brownish colors in this winter scene of the Uncompahgre Plateau in southwestern Colorado represent coniferous forests and woodlands (341). It is not possible visually to separate the various kinds of these forests except by inference from topographic position. One could reason that most woodlands at the lowest elevations and on south-facing canyon slopes would be juniper woodlands (341.1), that the intermediate forests on the broad plateaus and dip slopes would most likely be ponderosa pine (341.2) and that most of the coniferous forests on protected slopes at middle and upper altitudes would be mixed conifer (341.3) types. Note the sharpness with which the cleared juniper areas (400) southwest of Montrose, Colorado (arrow) are contrasted by the snow cover.

to be favored. As support imagery the S-190B shows some points of advantage and, had we the opportunity to test S-190B color infrared, it might well have been higher in the scale assuming adequate photo quality control and consistency. In addition, the black-and-white infrared showed advantages in selected discriminations and thus should be considered in a support role for visual interpretation.

It should also be recognized that S-192 is really a finer-tuned multispectral system than ERTS-1 and it is unfair to compare it in photographic mode. We were asked specifically to include the 1, 7, 9 color reconstitutions in our visual interpretation testing. For lack of funds and time after receipt of S-192 tapes, we were unable to include it in the digital analysis format where it might well have provided superior information if our parallel experience with ERTS-1 digital data can be taken as an indication of what to expect.

In considering these results as well as in designing new and further experiments, it is important to recognize that only point identification, not mapping, of natural vegetation analogs was tested in the previous experiments. This is only half of the mapping job. Delineation capability must also be assessed. The final "proof of the pudding" is, however, in identification because there are workable alternatives for minimizing problems of delineation.

Kinds of commission errors: In a combination of data from Tests One and Two, we considered the interpretability of specific analogs in terms of the kinds of confusion involved in the commission error categories. We established a threshold level of two commission errors per ten decisions on a single vegetation analog category as the possible confusion level above

which special training and care would be required or justified to minimize commission errors in interpretation. There is a significant analog-image type interaction. Thus, the best image type is a function of the subject of interest (Table 7).

The next table (Table 15) summarizes the problem analogs based on the above mentioned threshold concept. For this summary and analysis the results of Tests One and Two were combined and the combined results presented in Table 15. Observe that 341.1, pinyon-juniper; 341.2, ponderosa/Jeffrey pine; 347, mountain brush or chaparral; and 315, meadows are the problem analogs on which training and care of interpretation should concentrate.

1.6.2 MAPPING EXPERIMENTS

Mapping experiments are most difficult to conduct because any map is a generalization of reality and to a large degree the result is subject to the individual interpretation of mapper who must decide:

a. How to resolve gradients and intricate patterns with the legend system,

b. How to compromise these same patterns with a mapping intensity or level of generalization appropriate to the purposes for which the map is being made, and

c. When to ignore certain features as unimportant inclusions.

Except in the case of pure, distinct types that clearly exceed the minimum "intensity of delineation" standards, it is rare that any two experienced individuals will produce exactly the same map. If they correctly identify the subjects delineated within each boundary and reasonably assess the proportions of each within that boundary, their differences in delineation

Table 15. Vegetation Analogs Most Likely to be Confused in Visual Interpretation of Space Imagery

Photo Interpretation Identification	Ground Truth: Sa	J	B	P	W	A	S	X
Sa	XXX	+						
J	+	XXX	++	+			-	++
B		-	XXX	++				
P		-	++	XXX	++	+		+
W		+			XXX	-		++
A				+	+	XXX	+	+
S		-		-		+	XXX	+
X	+	++	+	-	+	-	-	XXX

Numeric Symbol	Vegetation Type	Alpha Symbol
315	Meadows	W
325.1	Sagebrush	Sa
341.2	Ponderosa/Jeffrey Pine Forest	P
341.1	Pinyon-juniper Woodland	J
341.4	Spruce-fir	S
342.4	Aspen	A
347	Oakbrush/Mountain Chaparral	B
	Other Vegetation Types	X

++ = Most likely
\+ = Moderate likelihood
\- = Some likelihood

are inconsequential--who is to say which map is correct and which is in error. If these decisions by the interpreter are accurate (identification and proportion of area), the data tabulation for all interpreters will add up to the same set of statistics regarding the kinds and amounts of features being mapped.

In the Sierra-Lahontan region we found it necessary to use widely diverse areas to get a representation of the necessary analogs while we could achieve this in a single transect of approximately 1,761 square kilometers in the Colorado Plateau region. All mapping experiments and comparisons were done in the latter region for this reason.

A set of mapping guidelines was followed in delineation and annotation (Appendix C). As each delineation was made its components were tallied on a standard form (Appendix C) along with time expended notations. Delineation was done on the combined basis of vegetation and land surface features so that identification provided both components of the legend. The key results of all this work are presented in the tables and discussion that follow.

1.6.2.1 <u>IMAGE TYPES DISCERNIBLE ON EACH KIND OF IMAGE</u>

One of our first experiments was to determine the number of kinds of images that could be discerned on each image type without regard to identification of the subjects represented. Such a test is meaningful and valid on the assumption that if one can discern a difference and thus delineate a subject area, there are many ways by which it can be accurately identified to provide useful information.

To make this comparison, an identical area of approximately 21-square inches was laid out on each image type. From this population, six one-square-inch samples were drawn. To provide direct comparability, the same six locations were used for each image type. Two experienced interpreters examined each square-inch sample and independently decided on the number of image classes that could be discerned within the designated sample area. They first did the "easy to discern" determination, compared results and discussed differences to agree on the number that their collective experience indicated could be repeatedly detected without problems of incomplete boundary location and consistency of recognition. This number was entered as the first observation for the square-inch sample area. They then repeated the process to decide on the total number of image classes that could possibly be discerned in the same sample area by considering subtle differences in density, color, or image texture. Notes were compared and a single decision again reached on the maximum number that could be practically interpreted in an operational setting; i.e., entire boundary definable and reasonable expectation that interpreters, working under the same set of mapping intensity guidelines, would be able to recognize each image type.

The average number of classes discerned in the six square-inch sample areas is tabulated in descending order by film type in Table 16.

These data enable a comparison of color versus black-and-white; for the "easy discernibility" class, color defined, 38 percent more kinds of images than black-and-white and 50 percent more for the "total possible" class. In this case note that S-190A color infrared and S-190B color were superior and that S-190A black-and-white red band was third even though in the identification testing this image type was either poorest or next to

Table 16. Earth Resource Discriminating Power Imagery From Space

Film Type	Number of Image Classes	
	Total Discerned	Easily Discerned
S-190A CIR	50	41
S-190B COLOR	40	29
S-190A Red	36	24
ERTS-1 CIR	31	29
ERTS-1 Band 5	30	19
S-190A IR	25	19
ERTS-1 Band 7	24	21

poorest image type. ERTS-1 color reconstitution was fourth; and while the infrared black-and-white images proved out well in the identification tests, they were rated on the bottom in terms of discriminating power.

1.6.2.2 COMPARATIVE RESULTS OF MAPPING

The comparative results of mapping provide a guide to the better image types in two ways: first, from information relevant to the amount of extractable information; and second, on the basis of costs of deriving the information. Table 17 summarizes the data relevant to these questions for each image type when mapped at the constant scale of 1:250,000.

Note first that ERTS-1 provided the highest percentage of "pure types", but this may be due to the higher level of generalization inherent in the poorer resolution of the image used and season of acquisition. The other image types are essentially the same as regards this indication of mapping intensity. The highest percentage of three-way complexes mapped was from the highest resolution image types, S-190B color and S-190A color infrared. In the former case the percentage was high (14 percent) because of resolution of the system. In the second case it was high (13 percent) because of the increased detectability of certain types resulting from the infrared band and the false color product. The other high percentage of three-way complexes was mapped on the Uncompahgre Plateau example of the S-192 color data. Here the reason was due to our mapping this example from 1:790,000 scale material and the fact that this image was particularly good in terms of vegetation type resolution. We were able to see and identify far more kinds of vegetation than could be mapped at such a small scale.

Table 17. Comparative Cost Factors to Analyze and Map from Space Imagery

Image Type	Man-hours Interp./ 2,000 Sq. Km.	Number Delin./ 2,000 Sq. Km.	Man-min./ 100 Delin.	Man-min. /100 Sq. Km.	% Pure Types	Avg. Boundary Score
ERTS-1 CIR	2.37	56	255	6.99	50	2.03
S-190A COLOR	2.56	84	182	7.67	35	1.69
S-190A CIR	3.56	86	247	10.67	30	2.08
S-190B COLOR	5.02	99	305	14.48	35	1.65
S-192 COLOR	1.40	43	224	4.18	30	2.23

The average boundary scores favored S-190A color and S-190B color with S-192 color averaging lowest. The number of delineations per 2,000 square kilometers is also an index of information content when mapping is done under the same standards. This tends to place S-190B color at the top, S-190A color and color infrared intermediate, and ERTS-1 and S-192 at the bottom in that order.

Cost factors are, of course, a function of the number of delineation and identification decisions that have to be made and how easily they can be arrived at. When imagery is poor, and of its nature generalizes the ground features, costs tend to be low but cost per unit of information may be high. Similarly, S-190B color looks very expensive in man-hours and S-190A color infrared more expensive than ERTS-1. If, however, one ratios the cost to information on the assumption that number of delineations per 2,000 square kilometers is an index of information content, the image types line up as follows:

Image Type	Ratio
S-190B color	0.50
S-190A color infrared	0.42
ERTS-1	0.43
S-192 color	0.30
S-190A color	0.30

There are, of course, other criteria of benefit and value. Without considerably more work it is difficult to determine which system the cost benefit really favors--except to recall that the two intermediate cost systems (S-190A color infrared and ERTS-1 4, 5, 7 color) were nearly always on top in accuracy of identification. These two systems also came out top and intermediate, respectively, in the discriminating power study (Table 16). These facts would strongly tend to throw the cost benefit in their favor because of

the higher reliability of the information derived--since the proof is in reliability of information, not delineation density.

1.6.2.3 <u>ACCURACY OF IDENTIFICATION IN MAPPING</u>

It was our original intention to use the high-flight RC-8 color infrared photography as a standard for judging the accuracy of both mapping and identification by the space imaging systems. This did not prove too successful because of the difficulty of deciding how best to generalize between the aircraft and the space systems and because we did not encounter enough examples of some types within the test belt of superimposed imagery to provide a sufficient sample size. However, for one second order, one third order, and four fourth order analogs, we were able to make a reasonably good comparison. This comparison for two strongly contrasting image types, S-190B color and ERTS-1 is presented in Table 18. In both cases we expected the accuracy at second and third level to be higher than at fourth level. This was true only for the S-190B color, not for ERTS-1. For all but the 320 (shrub/scrub) class, accuracy levels are quite acceptable, being lowest for 341 (coniferous forest). The 320 class was low because this is one of the most difficult classes in this particular region to discriminate. There was a strong tendency to confuse 320 with some of the 341 types. This may also be what pulled down the 341 accuracy. More importantly, these results show that space imagery can be interpreted to fourth level in some instances if the interpreter knows what to expect in the area. Had the area allowed a comparison of 324 (salt desert), 325 (shrub steppe), and 327 (macrophyllous shrub), it is our hypothesis from other interpretation work in the project that satisfactory results would have been obtained--especially had it been possible to incorporate multidate imagery and to evaluate the areas in stereo.

Table 18. Accuracy of Identification of Delineations in Mapping, Preliminary Data

IMAGE TYPE AND LEGEND LEVEL	PERCENT CORRECT	
ERTS-1 CIR		
320	50	
325.1		33
327.1		58
341	86	
341.1		67
341.2		100
S-190B COLOR		
320	71	
325.1		57
326.1		54
341	61	
341.1		59
341.2		38

1.6.3 STEREO INTERPRETATION FROM SPACE IMAGERY

Since our first successful experience with the stereoscopic interpretation of Apollo VI photography over southern Arizona, Dr. Poulton and many of his associates have been proponents for the use of stereoscopic interpretation of space imagery whenever possible. Upon our request, most of our Skylab imagery was taken with 60 percent forward lap, and we had done side lap stereo interpretation of ERTS-1 data in the early phases of that experiment. Routinely in our operational project work, we make use of the side lap area between orbits as a starting point in visual image interpretation of ERTS-1 data.

Our first experiment in stereoscopic interpretation was conducted with inexperienced students in connection with Identification Test One. In this experiment, ten of the interpreters were given a stereoscopic identification test of point data in the Colorado Plateau Test Region as a repeat of the monoscopic test they had taken some weeks earlier. The long delay was intended to compensate for any familiarity bias in the second stereoscopic test. S-190A color infrared images were used for the test. The working materials were enlarged to the point that the images would be at approximately the same scale when viewed under a magnifying stereoscope as the monscopic images when viewed without magnification.

The following overall results were recorded for the ten interpreters: Monoscopic interpretation, 82.7 percent; stereoscopic interpretation, 77.3 percent. The two sets of data were not significantly different when subjected to a paired "t" test (P=0.99). Two reasons are offered in explanation: (a) although the students had unimpaired stereo vision, none had had significant experience with stereoscopic interpretation; and

(b) more importantly none of the students were experienced in relating vegetation to its physical setting--they just did not know what to expect. The illustrated introduction to the natural vegetation was apparently inadequate to prepare them for interpretation of the stereoscopic model.

To assess whether the results of a trained interpreter might be better than those of the student group, one of the investigators took the same test. This individual had had extensive stereoscopic viewing experience and understood the relationships between vegetational zonation, landform, and elevation. His results are summarized below:

	Number of Correct Responses (maximum = 10)	
Category	Monoscopic	Stereoscopic
J - Pinyon-juniper	6	10
P - Ponderosa pine	8	10
W - Carex meadows	9	7
A - Aspen	7	10
S - Spruce-fir	5	7
X - Other vegetation types	5	7

Prounounced improvement in identification accuracy was noted for all categories but one. This category--sedge meadow (W)--always occurs in very small units and was sometimes difficult to see clearly on the stereo model. This limited comparison highlights the important role to be played by a trained interpreter when extracting image information from a complex landscape. Knowledge of the ecological relationships present in that landscape is essential to accurate interpretation. Under these circumstances, it was our hypothesis that stereoscopic interpretation will produce markedly improved results over monoscopic interpretation.

In connection with the more comprehensive mapping experiments, we set about to test this hypothesis.

1.6.3.1 STEREOSCOPIC EVALUATION OF GROUND RESOLUTION

Each image type was viewed at two scales for this test. Four kinds of a natural resolution target were evaluated for clarity (++ = very clear or obvious; + = evident; - = not evident). These were converted into a numerical score as shown in Table 19. The S-190A color and S-190B color were best and the only place where stereoscopy gave an advantage was in some of the linears.

1.6.3.2 STEREOSCOPIC PERCEPTION OF RELIEF CHANGE

We next set about to determine what magnitude of relief differences a person with good stereo perception could actually see as a three-dimensional model with each kind of space imagery. Side lap stereo was used for ERTS-1. All of the features listed in Table 20 were scored by the same method as the ground resolution targets and numerical scores were computed in the same way. This showed S-190B color superior to other systems. On S-190A color and the S-190B one could see relief differences as slight as 200 feet. The perception of relief was a function of the rate of change but even in relatively level to rolling macrorelief, one could see a true stereo model down to a threshold of 200 to 225 feet per mile. This perception capability is highly important and of great value in identification of vegetation analogs through relationship to landform, slope, and position on slope. While conducting this test it was evident that under certain conditions monoscopic viewing could give a depressional perspective when in fact one was looking at strongly hilly macrorelief. Such misconceptions of landform did lead to identification errors of substantial magnitude--for example, erroneously calling deciduous aspen and mountain meadows sagebrush steppe and salt desert vegetation types when viewed monocularly.

Table 19. Evaluation of Ground Resolution at Two Scales for Each Image Type

Features Judged	ERTS-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
Cortez--Business District	3	1	1	2
Cortez--Residential District	5	1	4	1
Dolores--Townsite	4	2	2	1
Escarpments and linears	2	1	3	1
Average Ground Resolution Score with its standard error	3.50 ± .91	1.25 ± .35	2.50 ± .92	1.25 ± .35

Relative Score: (1 Best, 5 Poorest)

1 = ++ Both scales = Very clear or obvious

2 = ++ One scale + other scale

3 = + Both scales = Evident

4 = + One scale - other scale

5 = - Both scales = Not evident

Table 20. Evaluation of Relief Detection by Stereo at Two Scales for Each Image Type

Features Judged	ERTS-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
Elevation change of 65'	5	5	5	5
Elevation change down drainage 600'	1	1	1	1
250' escarpment	3	2	4	2
300' escarpment	1	1	1	1
Less than 200' escarpment	3	2	5	1
1,000' escarpment	1	1	1	1
400' hill on top of mesa	1	2	1	2
600' hill on top of mesa	3	4	4	2
850' ridge and valley	1	1	3	1
200'/mile valley floor	5	4	3	3
225'/mile dip slope	1	2	2	1

Relative Score: (1 Best, 5 Poorest)

1 = ++ Both scales = Very clear or obvious
2 = ++ One scale + other scale
3 = + Both scales = Evident
4 = + One scale - other scale
5 = - Both scales = Not evident

Table 20. (Continued)

Features Judged	ERTS -1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
200'/mile toe slope.	2	1	2	1
170'/mile bajada	4	3	4	3
Elevation difference, high peaks, 8,400' to 9,300'	1	2	2	1
Slope break 2950'/mi.-750'/mi.	2	1	4	3
Slope break 750'/mi.-350'/mi.	2	3	2	1
Average Relief Detection Score with its standard error	2.25 ± .36	2.19 ± .32	2.75 ± .36	1.81 ± .29

Relative Score: (1 Best, 5 Poorest)

1 = ++ Both scales = Very clear or obvious

2 = ++ One scale + other scale

3 = + Both scales = Evident

4 = + One scale - other scale

5 = - Both scales = Not evident

1.6.3.3 STEREOSCOPIC IMPROVEMENT OF IDENTIFICATION DECISIONS

By reassessing monocular mapping and identifications of both vegetation and landform features in the same 1,761 square kilometer area of each imagery type except S-192, we were able to make a good assessment of the benefits from stereo interpretation. Table 21 shows the amount of delineation and identification change made by stereo examination at a scale of 1:250,000. This table suggests that there are important differences among imagery types as regards the benefit from stereo viewing. More changes in boundary were made with ERTS-1 and S-190A color than with the other imagery types. Many of these boundary changes were of substantial areal significance. Most of them were made either in areas of undulating to slightly hilly macrorelief or in areas where the image characteristics gave the impression of gentle relief when in fact the subject was strongly hilly to mountainous. This is particularly helpful in the case of isolated buttes and small mountains systems. Also in the gentler relief areas one can relate a vegetation change to a break in relief when such is impossible in mono viewing. The changes in identifications were substantial for S-190B color.

The low contribution of stereo to S-190A color infrared is probably due to the poor resolution characteristics of the particular image used in this experiment. The large number of changes in landform classification with the S-190B color when viewed in stereo is most likely due to its higher resolution and the fact that by viewing in the stereo model, more of the features of relief can be seen and more of the vegetation pattern explained.

We next looked at the exact nature of the changes in identification resulting from stereoscopic viewing. These comparisons are shown in Table 22. Part of the change in the 2.3 class was the result of calling the lands more

Table 21. Change in Monocular Delineation and Identification by Stereo Examination at 1:250,000 Scale in a 1761 Sq. Km. Area

Image Type	Line Change		Identification Changes	
	cm.	Ratio of Delin. Den.	Landform	Veget. Ident.
ERTS-1	9.3	0.1660	15	12
S-190A CIR	6.5	0.0756	2	6
S-190A COLOR	9.1	0.1083	12	9
S-190B COLOR	6.0	0.0606	30	16

Table 22. Percentage Changes (Improved Confidence of Decision) by Stereo Interpretation of Space Imagery (All Types Considered)

Ground Cover Analog Class		Land Surface Class	
Item	Percent Changed	Item	Percent Changed
130, Rockland	11.6	1.2 Flat, riparian bottom-lands	1.9
310, Herbland	14.0	2.2 Undul./Rolling, bottom-lands	1.9
320, Shrub/Scrub	4.6	2.3 Undul./Rolling, planar surfaces	43.3
325, Shrub Steppe	7.0	2.4 Rolling, slope systems	5.7
327, Macrophyl. Shrub	25.6	3.3 Hilly, planar surfaces	3.8
341, Conifer Forest	24.9	3.4 Hilly, slope systems	17.0
342, Hardwood Forest	7.0	4.4 Mountainous, slope systems	26.4
510, Agric. Cropland	2.3		
	100.0		100.0

flat in mono interpretation and to the changes in the hilly and mountainous classes. Changes were made from hilly to mountainous. A stereo classifications into mountainous of some of the lands formerly considered in class 2.3 accounted for some of the large differences between mono and stereo identification. Some of the mountainous relief difference could not be judged by monocular interpretation.

Much of the change in 130, rockland, resulted from being better able to perceive mountainous rocklands in stereo. The perception of lowland flatlands contributed to some of the change into 310, herbland, classifications. Most of the change in 327, macrophyllous shrub, and 341, coniferous forest, resulted from being better able to define the true 327 areas in stereo since they are higher plateau and hill land related. There was a tendency to overestimate 327 where it occurred adjacent to 341 and particularly to underrate the latter where stands were open. Some of these errors were corrected by landform relationship in stereo viewing. While one could not see individual conifer trees, the 341.3, mixed conifer, class could be more accurately identified in stereo because of the strong relationship to steep slopes, valleys, and high hill and mountain positions that this type occupies.

While more in-depth studies by larger numbers of experienced interpreters could refine and improve upon measurements of value from stereo, we feel that these results are sufficient to stimulate more serious consideration in use of stereoscopic interpretation of space imagery where natural vegetation and soil conditions are the main points of concern.

1.7 AN OPERATIONAL SYSTEM FOR EARTH RESOURCE ASSESSMENT

In an effort to define an effective operational system for amalgamation of space and aircraft remote sensors into an efficient and cost-effective operational system for inventory, analysis, and monitoring of earth resources and land use, a highly generalized flow diagram is presented (see Figure 10 and a detailed expansion in Figures 10a, 10b, 10c, and 10d).

The generalized flow diagram of Figure 10 is essentially self-explanatory, but a few points may require clarification. A ground truth mission is scheduled deliberately relatively early in the flow chart. In practice, ground truth missions come into the system at many points. It is better to emphasize their role by inclusion in the direct flow-line rather than to de-emphasize such an important component by placing it in a multi-focused peripheral loop. The first ground truth mission, in a reconnaissance mode, may actually have to be performed as a part of the background work in some projects. It can be a part of any subsequent stage through "refined interpretations."

This generalized flow diagram emphasizes another important concept--namely, that the first-cut interpretation in some cases is done most effectively by knowledgeable and experienced interpreters rather than by computer analysis.

Finally, in the generalized treatment, the role of "feedback" deserves some special attention. Almost without exception in the operational mode, feedback may start at any stage beyond the initial stratification to bring about refinements, to improve adaptation to the specific problem situation, and to enhance performance. Feedback is, of course, particularly

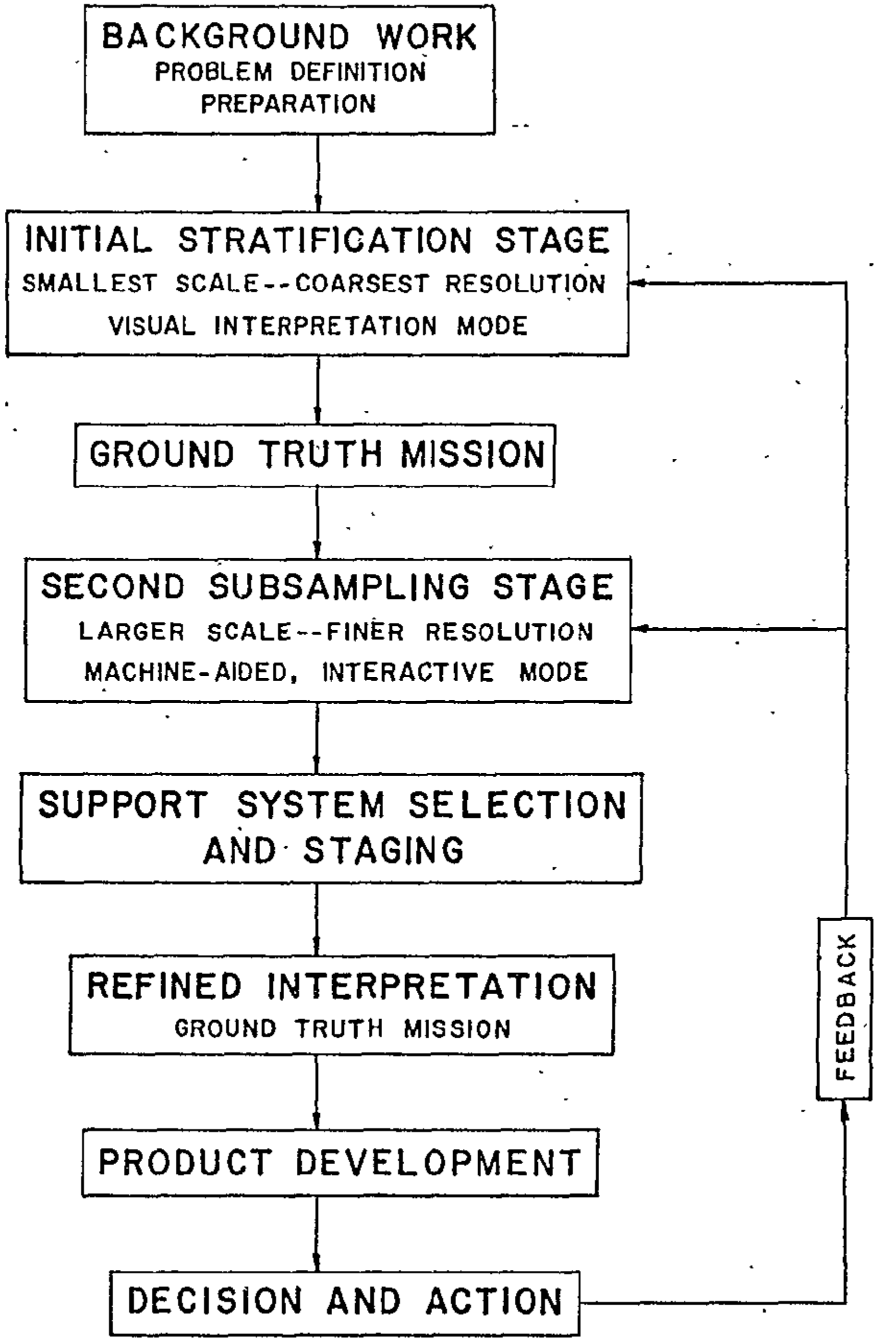


Figure 10. A generalized flow chart for an operational remote sensing system involving space acquired imagery.

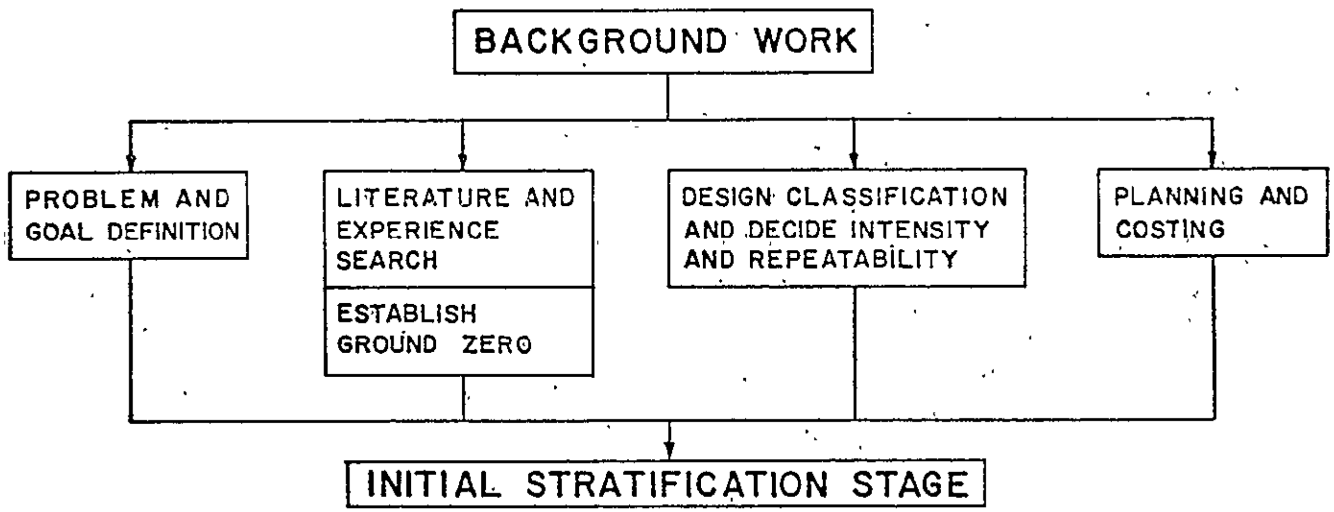


Figure 10a. Some important details of background to set the stage for effective remote sensing of earth resources subjects.

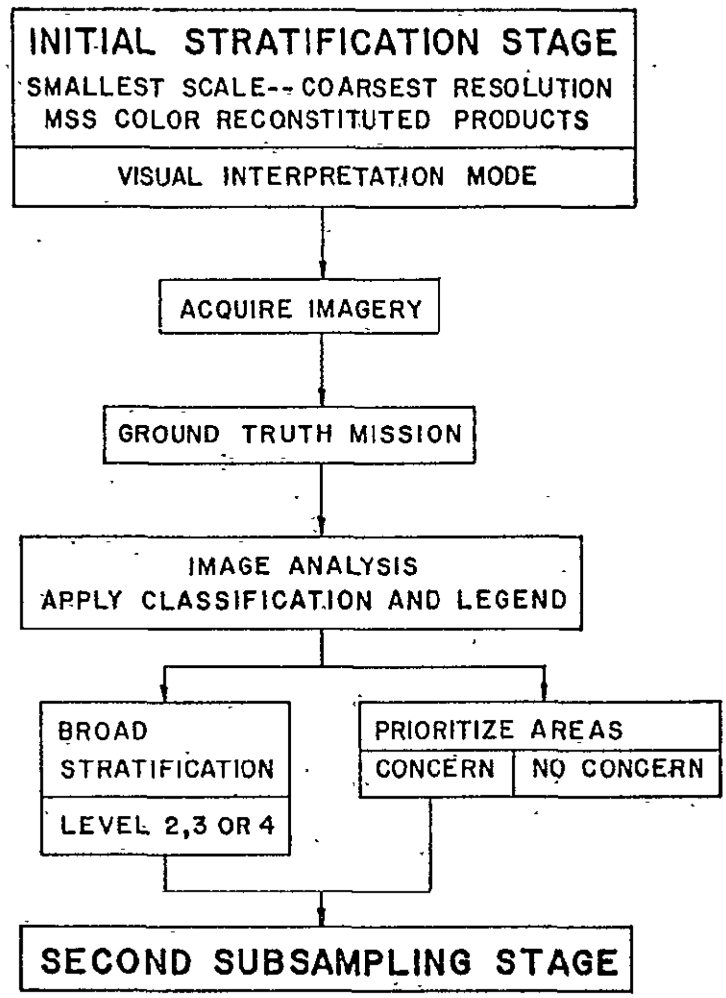


Figure 10b. The initial stratification and area priority stage of inventory.

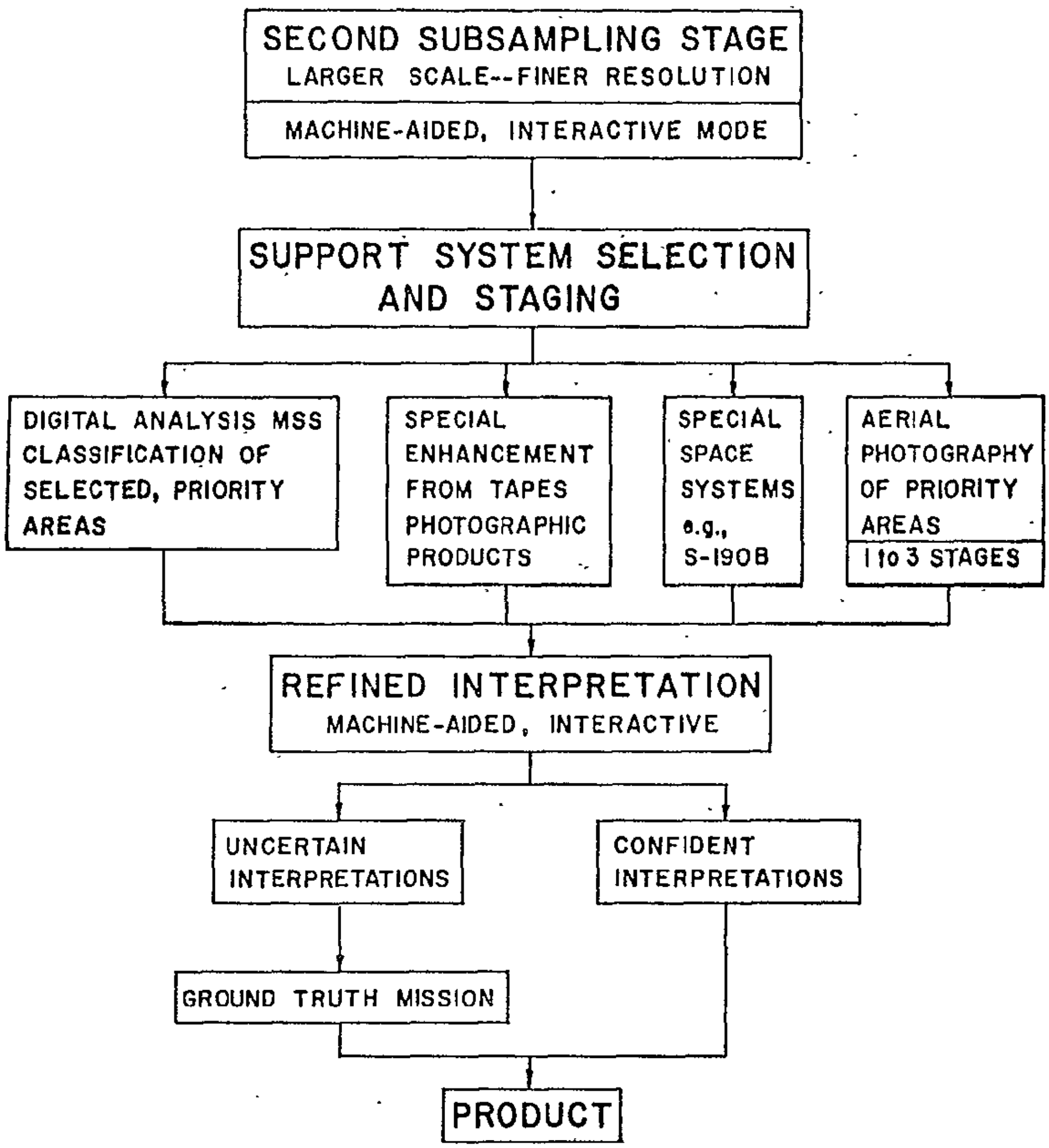


Figure 10c. The alternative selection and in-depth interpretation stage.

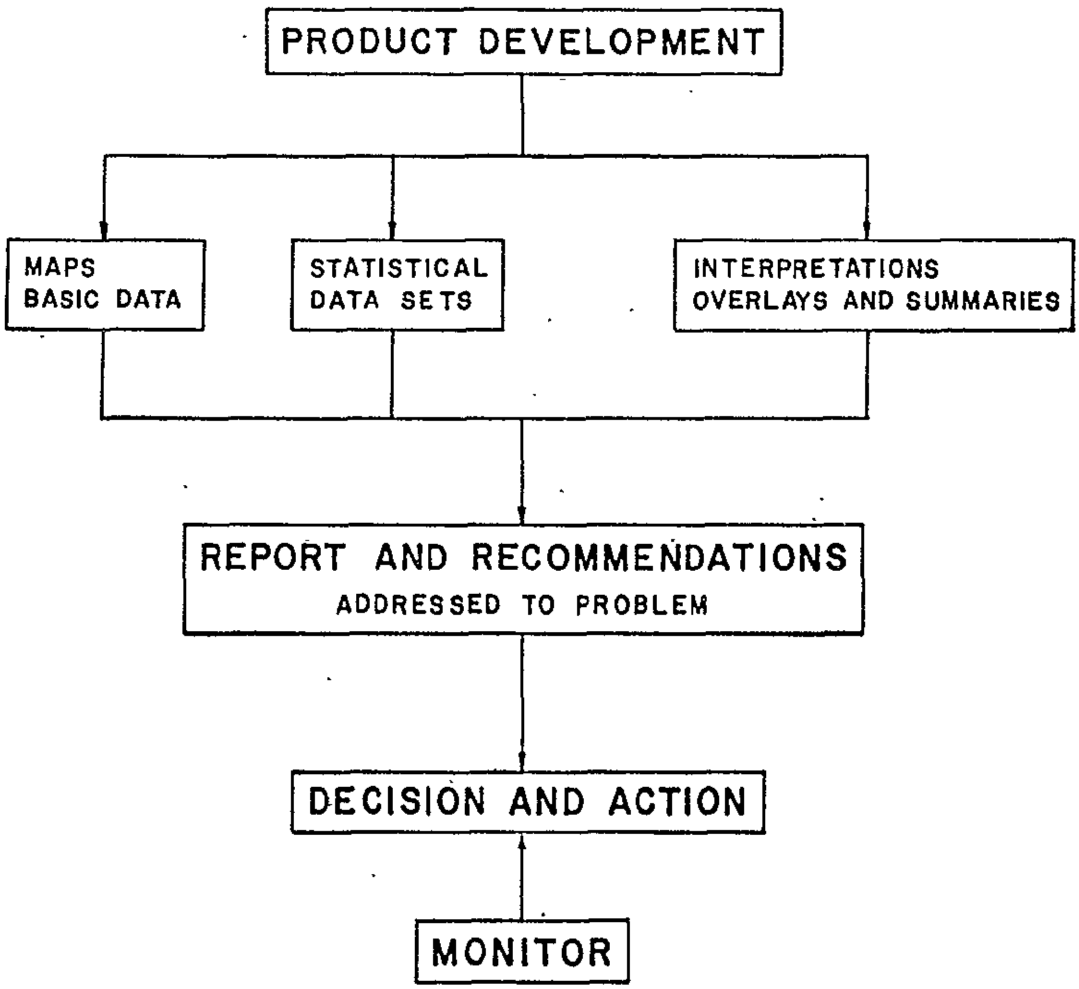


Figure 10d. The product development presentation and action stages in the use of remote sensing systems.

important when one reaches the monitoring component of the "decision and action" block.

Some of the major components of background work are specified in the expanded flow diagram of Figure 10a. The various functions in this unit should be self-evident but disregarding or side-stepping of important components in this stage sometimes jeopardizes successful application of the system.

The block representing those factors of design, classification, intensity, and repeatability also includes the idea of adopting the legend system. Following are the main advantages of the legend system we have devised and perfected by deligent modification and testing plus sessions to seminar and critique the legend by people actively involved in practical, operational use of the system. It has gone through numerous revisions and extensive field verification. The legend has evolved into its present form demonstrating its practical usefulness for application to space and high-flight image analysis after having gone through a rigorous and critical development process. The main advantages of the system are:

a. It is based on divisive logic that is consistent with a growing understanding of earth resources and upon consistent criteria for differentiation by visual stimuli among classes at each hierarchical level.

b. It accommodates in a single coherent system the natural vegetation, vegetation modified by intent with a permanent management goal, barren lands, all water resources, as well as those land uses that have permanently altered the nature

of the Earth's surface, i.e., urban, industrial, transportation, and utility distribution, and extractive industries.

c. By being ecologically rather than urban-industrially orientated, it characterizes the landscape features on a natural basis that is free of land use bias.

d. The system thus provides a superior basis for treating the multiple land uses so common in the "wildlands" situation such as the case where the same piece of land is used for forestry, range, watershed, wildlife, and recreation. To knowledgeable resource ecologists, these potentialities for use are often self-evident in the description that the legend system gives of specific landscapes.

e. It is numerical and thus highly computer compatible.

f. It is conceived on a consistent logic through the fourth, fifth, and even to the sixth hierarchical level.

g. It allows easy and consistent agglomeration from the finest to the most generalized category.

The initial stratification stage (Figure 10b) is largely determined by the nature of the problem being attacked and the information needs being met through remote sensing. For problems where a regional perspective is needed or a land use interrelationship is to be portrayed, space imagery is often ideal. For some problems, however, the initial small-scale, stratification stage may best be performed on high-flight aerial photography. In the initial stratification stage it is also important to emphasize the need to do ground truth and overflight missions with imagery in hand.

Especially when working with space imagery the first two intensity levels of stratification should consider the appropriateness of an ecological province (or subregion) breakdown followed by a second-order stratification into land systems after the technique that is widely used in Australia. Following this, the third-order stage is delineation into appropriate levels of an hierarchical legend system similar to the one we have devised and proven through extensive use. For some projects this latter will represent the first order of stratification.

One of the most important features or concepts of space and high-flight image application is exemplified in the "prioritized areas" function of the initial stratification stage. By the application of these techniques, one quickly defines the areas of no concern so that all energy at an early point is focused on those important landscapes that are truly relevant to the problems at hand. This feature is a great saver of dollars and both scientific and managerial manpower.

In the second subsampling stage (Figure 10c) one moves to larger scale and/or finer resolution; and machine-aided, interactive interpretation becomes appropriate if not essential for maximum effectiveness of the system.

Strong emphasis should be placed on "support system selection and staging." At this point, the results of research similar to those reported here become paramount in making the proper choices among operational support systems. Dr. Poulton's accumulated experience to this point strongly suggests that, if space imagery is appropriate as the initial stratification stage, the ERTS MSS system is ideal for such applications. Supporting this system then, in the second subsampling stage, one has at least four highly

viable options. Remember that this stage follows the prioritizing of areas of concern. Within these areas then, the options become first, digital analysis of MSS data similar to ERTS-1 or possibly, with de-bugging and refinement, systems like the S-192. A second option which we in Earth Satellite Corporation are beginning to use extensively is the special enhancement and reprocessing of ERTS-1 data from the magnetic tapes to produce an improved photographic product at scales from 1:400,000 to 1:100,000. These images can be somewhat "tuned" to the needs of second-level analysis in areas of critical concern. A third option is use of special space systems such as the Skylab S-190B where higher resolution is needed because of the nature of problems being addressed.

A little-used option with high potential is visually interpreting stereo imagery from space, and still another option employs multidate or multi-season imagery. This requirement is another strong point in favor of an unmanned system such as ERTS-1 as the basic earth resource monitoring system. When one considers the practical problems encountered in getting a desired set of multidate imagery, superimposed over a clearly defined pair of interregional test sites, the advantages of a continuous running or programmable sun-synchronous system can be easily demonstrated. While, for natural vegetation applications, nine-day frequency of repeat coverage will rarely if ever be needed, there were many times during our ERTS-1 and Skylab experiments when a nine-day repeat cycle would have given us imagery we critically needed. Slippage of nine days around a critical stage of plant development can usually be tolerated, 18 days often not, 36 days is of marginal value for many functions in plant assessment.

Finally, but certainly not of least importance, conventional aerial photography in a multistage mode will always have a role to play in any comprehensive earth resources inventory and monitoring system that has as one of its goals contribution to resource management. The scale and spatial resolution of systems used under this option are highly dependent on the kinds of problems addressed. For example, if the solution of rangeland resources problems is approached with the intent of fully capitalizing on remote sensing capability, certain components of the problem require imagery at larger scales of 1:1,000 or 1:600 and with stereo overlap. These needs can hardly be met from presently available, civil applications space technology. At the present time, we feel that while digital analysis of ERTS-1 MSS data can be effectively done at a quasi scale of approximately 1:24,000 looking at 0.4 hectare units of land, this multispectral system cannot meet all of the requirements for assessing many natural vegetation management and soils stability problems.

Having selected the appropriate support systems and designed a multistage approach compatible with the problem situation, refined interpretation moves ahead to produce both certain and uncertain inventory decisions. A ground truth mission comes back into the loop as the uncertainties are removed or reduced to a tolerable level.

The product development block (Figure 10d) is an integral part of the remote sensing application package in the context of map preparation, derivation of statistical sets of necessary data and the interpretations that give the data and maps relevance to the problems to be solved. These actions lead to reports and recommendations that carefully address the problem. This ensures that the project objectives can be realized in a

rational decision and action program--one that is effectively monitored to fine-tune and adjust the program and ensure complete success in problem solving.

To the question, "Is such an operational program feasible?" we merely respond that Earth Satellite Corporation is now using ERTS-1 data, and in some cases Skylab imagery, together as appropriate with aerial photography for solving real problems. Such applications have taken place in the United States and on at least two continents other than North America. Many of the ideas embodied in the above flow diagram have been field tested in these kinds of operational projects. In our opinion, space-born remote sensing systems have already been proven operational. A significant number of projects are now moving ahead in developing nations, and in others where the resource base is not well understood, with a speed and at a cost that could not be approached--in some cases not even considered--if we lacked the option of doing the first-phase analysis by the interpretation of space imagery.

2.0 RICE ANALOG STUDY

2.1 BACKGROUND

One of the most comprehensive photographic experiments ever conducted took place during the NASA Skylab satellite missions. At no previous time in history had such a carefully planned and executed photographic study been performed that extended over such a wide range of ground sites, covered a range of dates, incorporated systems which had been tried prior to the mission in extensive simulated earth orbital tests, utilized spectral bands that had been selected from years of exhaustive photographic research, and employed a vehicle and personnel that had been prepared and trained so completely for such an experiment. In addition, the support efforts that were organized to collect concurrent aerial photos and ground data were more comprehensive than ever before arranged.

For these reasons the data available for this study are without a doubt of the highest quality and are supported by more information on conditions of the ground scene and performance of the system than any previous photo study.

The data derived from the Skylab photographic study (Earth Resources Experimental Package, EREP) provide information of far-reaching significance in defining a system that eventually will photograph the earth at scheduled intervals from orbital altitudes.

Another equally rewarding study was the NASA Earth Resource Observation Satellite (ERTS-1) experiment using many of the same techniques

as the Skylab EREP study but from an unmanned satellite. That experiment was conducted over a longer period of time and obtained considerably greater volumes of data.

The present investigators have had the privilege of contributing to both the Skylab and ERTS experiments and this report is based on those studies. The contract under which this work was funded utilized Skylab data and supporting NASA aircraft photography and this report will address those data primarily. However, data from other sources including the ERTS-1 experiment will be utilized where those data sources will provide vital information not obtainable from Skylab photos.

The data obtained during both the Skylab and ERTS experiments will be most helpful in defining the satellite remote sensing systems of the future. That system will most probably utilize many of the components and techniques employed in those experimental systems in a combination of manned and unmanned satellites each providing a unique part of the operational Earth Observation Satellite (EOS) system.

Our investigation was divided into two sections; one dealing with developing a uniform mapping legend and techniques for interpreting natural vegetation complexes and the other dealing with evaluating rice crop production in California and Louisiana.

2.2 PROBLEM STATEMENT

At the outset we established the following problem statement for the second section of this investigation as noted earlier.

INVESTIGATE THE USEFULNESS OF SKYLAB EREP DATA AND AIRCRAFT PHOTOGRAPHY FOR MONITORING RICE CROPS IN CALIFORNIA AND LOUISIANA FOR:

1. Crop Identification
2. Crop Vigor and Stress Evaluation
3. Rice Yield Indicators for use in multistage sampling techniques.

2.3 APPROACH

2.3.1 COLLECT SKYLAB EREP DATA FROM THE S-190A, S-190B AND S-192 SYSTEMS DURING THE POSSIBLE DATA PASSES AT SPECIFIED TIMES IN THE RICE CROP GROWING SEASON

A standing order was submitted for S-190A, S-190B and S-192 data from Skylab EREP data passes over a test site in the Northern Great Valley of California and an analogous site on the coastal plain of Louisiana. Because certain critical crop events occur at specific times during the growth cycle in each area, we requested coverage to coincide with those periods. Coverage was requested starting with soil preparation and extending through harvest at as many of the crop event dates as possible depending upon EREP data passes. Table 23 lists the crop events and nominal dates. Tables 24 and 25 list the data used in the various tests conducted in the investigation.

2.3.2 TAKE AERIAL PHOTOS AND COLLECT GROUND TRUTH DATA AT SPECIFIED LOCATIONS AND TIMES IN THE RICE GROWING AREAS

It was planned to collect aerial photos and ground data concurrent with EREP data passes and at other critical times in the crop calendar. A preliminary schedule was laid out during the prelaunch phase of the investigation.

C, 2

Table 23. Requested Dates of Coverage

CROP EVENT	CALIFORNIA	LOUISIANA
Soil Preparation	1 April - 1 May	15 March - 15 April
Flooding	20 April - 20 May	1 April - 1 May
Emergence	1 June - 15 June	15 May - 1 June
Full Grass	15 July - 15 August	1 July - 1 August
Heading	15 August - 15 Sept.	1 August - 1 Sept.
Harvest	1 October - 1 Nov.	1 Sept. - 30 Sept.

Table 24. Images Used for ERTS/Skylab Interpretation Tests of Agricultural and Natural Vegetation Features

MISSION	SENSOR	TEST AREA	DATE	IMAGE ID	FILM -FILTER/WAVELENGTH INTERVAL, μm
ERTS-1	Multispectral Scanner (MSS)	Sacramento Valley, CA	May 28, 1973	1309-18174	Band 5/0.6-0.7 Band 7/0.8-1.1 Color Composite -- Bands 4,5,7/0.5-1.1
			Sept. 13, 1973	1417-18161	Band 5/0.6-0.7 Band 7/0.8-1.1 Color Composite -- Bands 4,5,7/0.5-1.1
		Colorado Plateau	Aug. 16, 1973	1389-17195	Band 5/0.6-0.7 Band 7/0.8-1.1 Color Composite -- Bands 5,7/0.6-1.1
SKYLAB 2	S-190A Multi-spectral Photo-graphic Camera (MPC)	Sacramento Valley, CA	June 3, 1973	(roll-frame) 05-157 02-157 04-157 03-157	Pan-X B/W (SO-022) - BB/0.6-0.7 IR B/W (EK 2424) - DD/0.8-0.9 High Resolution Color (SO-356) - FF/0.4-0.7 Color IR (EK 2443) - EE/0.5-0.88
SKYLAB 3	S-190A Multi-spectral Photo-graphic Camera (MPC)	Colorado Plateau	August 3, 1973	23-003 20-003 22-003 21-003,004	Pan-X B/W (SO-022) - BB/0.6-0.7 IR B/W (EK 2424) - DD/0.8-0.9 High Resolution Color (SO-356) - FF/0.4-0.7 Color IR (EK 2443) - EE/0.5-0.88
		Sacramento Valley, CA	Sept. 12, 1973	41-140 38-140 40-140 39-140	Pan-X B/W (SO-022) - BB/0.6-0.7 IR B/W (EK 2424) - DD/0.8-0.9 High Resolution Color (SO-356) - FF/0.4-0.7 Color IR (EK 2443) - EE/0.5-0.88
	S-190B Earth Terrain Camera (ETC)	Colorado Plateau	August 8, 1973	83-309	High Resolution Color (SO-242) - none/0.4-0.7
		Sacramento Valley, CA	Sept. 12, 1973	86-320	High Resolution Color (SO-242) - none/0.4-0.7

Table 25. Aerial Photography Used for Support of Skylab Tests of Rice Crop Areas

Source	Frame Size	Test Area	Date	Mission No.	Film Type	Scale
NASA	9" x 9"	Marysville	11 June 73	73-093A	Color IR	1/2" = 1 mile
NASA	9" x 9"	Marysville	5 July 73	73-111	Color IR	1/2" = 1 mile
NASA	9" x 18"	Marysville	5 July 73	73-111	Color IR	2" = 1 mile
NASA	9" x 9"	Marysville	12 Sept. 73	248	Color IR	1/2" = 1 mile
NASA	9" x 9"	Marysville	12 Sept. 73	248	Color	1/2" = 1 mile
NASA	9" x 9"	Marysville	10 Oct. 73	73-173	Color IR	1/2" = 1 mile
EARTHSAT	9" x 9"	Marysville	29 Aug. 73	8-29	Color	1" = 250'
EARTHSAT	9" x 9"	Marysville	29 Aug. 73	8-29	Color IR	1" = 250'

Table 25. (Continued)

Source	Frame Size	Test Area	Date	Mission No.	Film Type	Scale
EarthSat	70 mm, 9" x 9"	Louisiana	3 June 73	6-3	Color, CIR	1" = 250'
EarthSat	70 mm, 9" x 9"	Louisiana	29, 30, June 73	6-29, 6-30	Color, CIR	1" = 250'
EarthSat	70 mm, 9" x 9"	Louisiana	7 July 73	7-28	Color, CIR	1" = 250'
EarthSat	70 mm, 9" x 9"	Louisiana	11,13,14 Aug. 73	8-11,8-13,8-14	Color, CIR	1" = 250'
EarthSat	70 mm, 9" x 9"	Louisiana	19 Aug. 73	9-19	Color, Cir	1" = 250'

Because of changes in launch dates and schedule changes for EREP data passes, we were required to rearrange our data collection schedule for aerial photography and ground observation. The actual data collected is covered in section 2.5, Date Received and Dropouts. These data were used to devise multistage sampling schemes and as "ground truth" over the test farms.

2.3.3 PERFORM PHOTO INTERPRETATION OF EREP AND AIRCRAFT PHOTOS AND EVALUATE THE CONTRIBUTION EACH INPUT MAKES TO CROP MONITORING

For the data obtained, a set of photo interpretation tests was organized to evaluate the usefulness of each EREP photo system for the problems defined. In an interim report submitted on this project[1], a series of systematic photo interpretation tests were conducted evaluating quantitatively the comparative interpretability of Skylab EREP and ERTS MSS data for land use identification in an agricultural area and crop identification in the rice analog sites. We also evaluated the usefulness of each data source for estimating crop vigor and the presence of stress indicators. These data comprise the primary quantitative information on the rice analog study.

A limited investigation was made of the ability of photo interpreters to measure acreage of rice fields and to estimate yield of rice fields by photo interpretation on the EREP photos in conjunction with aircraft photos.

[1] A Comparison of Skylab and ERTS Data for Agricultural Crop and Natural Vegetation Interpretation, July 1, 1974.

2.4 SCOPE

2.4.1 STUDY SITE SELECTION PROCEDURE FOR CALIFORNIA AND LOUISIANA

In order to provide a realistic test of the usefulness of Skylab data for rice crop analysis, we selected two primary sampling regions in the United States that were typical rice growing areas with somewhat different environmental characteristics to provide variability in testing conditions.

The two regions were the Northern Great Valley (Sacramento Valley) of California and the Louisiana Coastal Plain. These primary sampling sites were selected because of the extensive areas in each that were committed to rice culture and the fact that in the California area very few pest problems and other yield-limiting agents were active, while in Louisiana several potentially severe yield-limiting agents were active. In Louisiana these included rice diseases, weed infestation and weather problems, while in California no diseases of consequence were active and severe weather factors were usually not a problem. Weed competition did, however, have an influence in both California and Louisiana. Weather problems in Louisiana not only caused lodging (blow down) of the grain by high winds and heavy rainfall, but it also caused a considerable reduction in useable satellite data because of cloudy sky conditions that prevailed over the rice test sites during some of the scheduled EREP data passes.

After considering the planned Skylab ground tracks over the rice test regions, we selected specific test areas in each region (primary sample units, PSUs) where our research would be concentrated and where a variety of crop conditions and crop types could be found. In each area

we arranged for cooperation from local extension workers and farmers to obtain ground truth data in conjunction with EarthSat project staff. The location of these test regions can be seen in Figures 11 through 14.

2.4.2 PRIMARY SAMPLE UNIT (PSU) DESCRIPTION

2.4.2.1 LOUISIANA COASTAL PLAIN

The south central Louisiana test region is located on floodplains of the Mississippi River. Its climate is controlled by the proximity to the Gulf of Mexico and its latitude. The summers are warm and humid with precipitation often falling from thunderstorms. The winters are also moist; however, temperatures can dip to below freezing. Severe storms often lash the coastal regions and bring hurricane-force winds that reach far into the interior regions.

The major crop types include rice, soybeans, sugar cane, corn, pasture, and cotton. Specifically for rice there are two major types: medium and long grained. The predominant varieties are Nato, Nova, Blue Bonnet, and Zenith. A majority of the rice is seeded in April and May; however, the seeding season can extend from the middle of March through the end of June depending on variety and conditions. Seeding in 1973 was delayed until the end of May by unseasonal rains which kept the ground too moist to work properly. Seeding is done by two basic methods, grain drilling or airplane broadcast. Fertilizer application is done initially by drill or airplane and later in the season another application (top dressing) is done by airplane. Broadleaf and grass type weeds are a problem dependent on cultural practices. Diseases such as stem or leaf blast are a problem and can severely limit the rice yield. Insects, primarily root

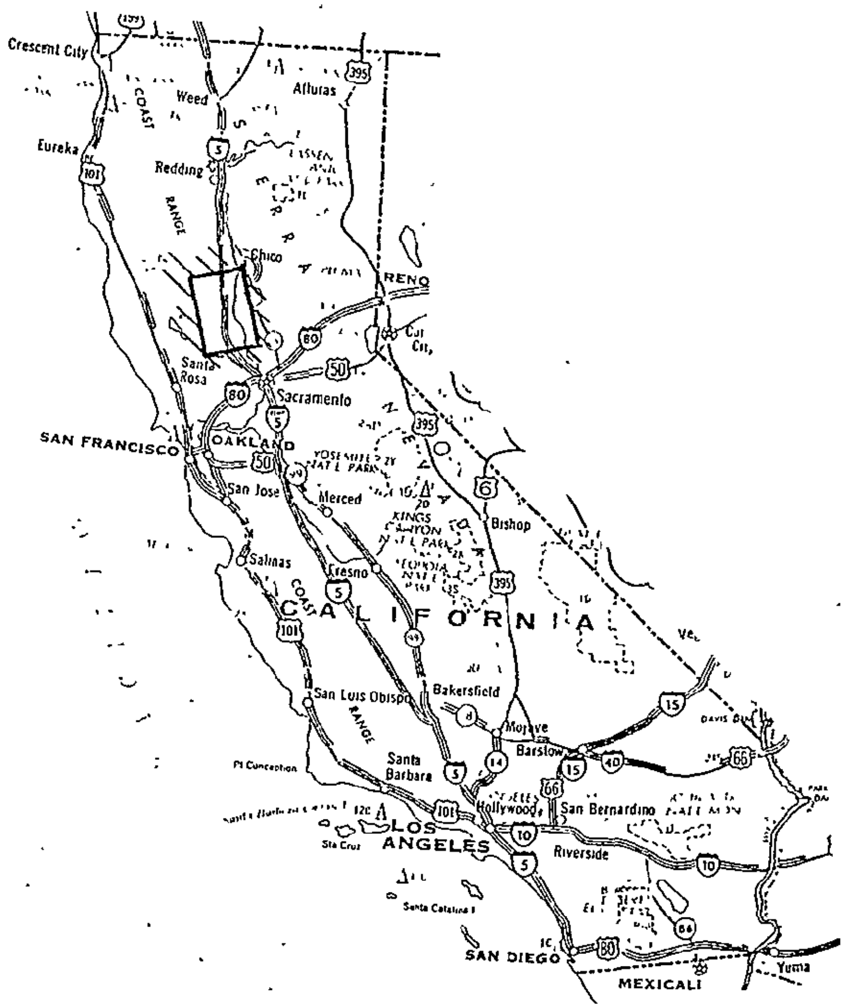


Figure 11. Northern Great Valley Test Region.

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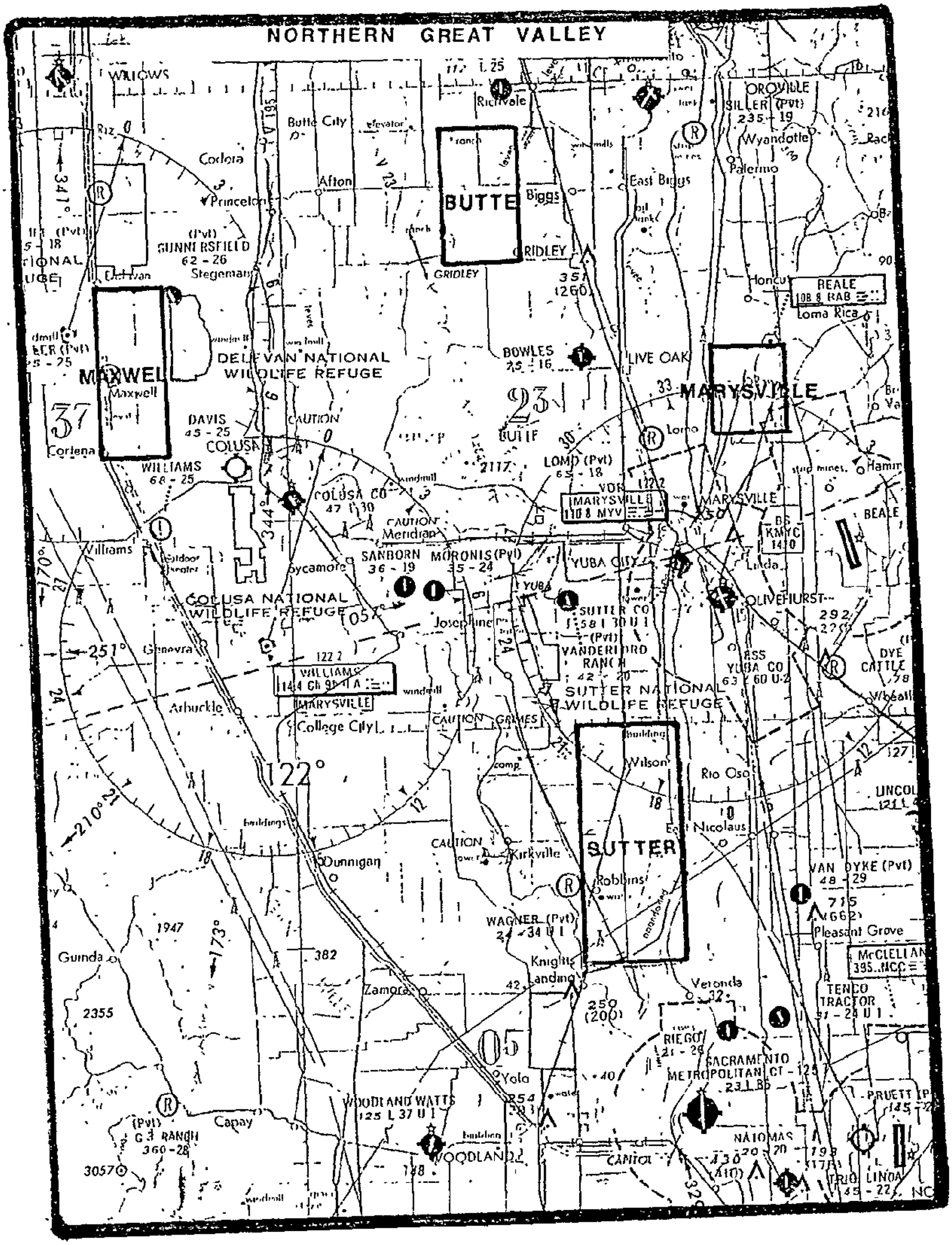


Figure 12. Primary and Secondary Sample Units, Northern Great Valley.

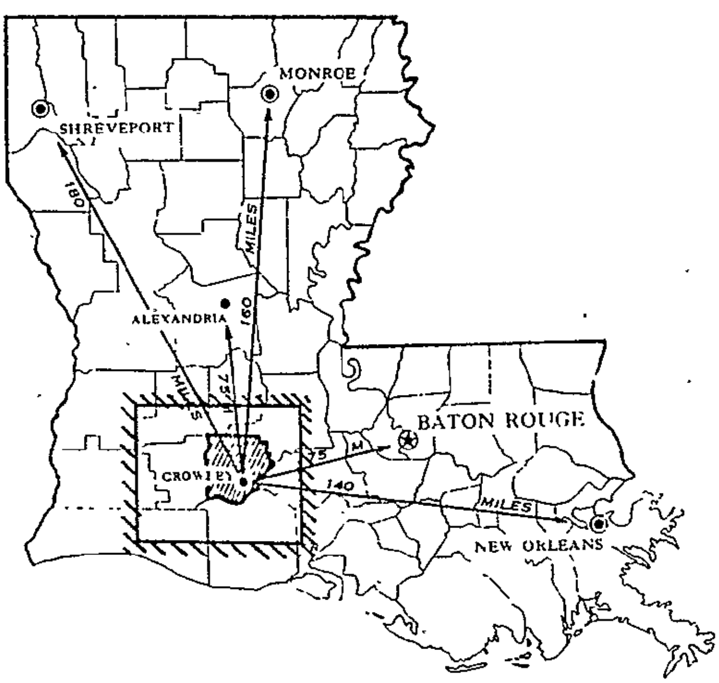
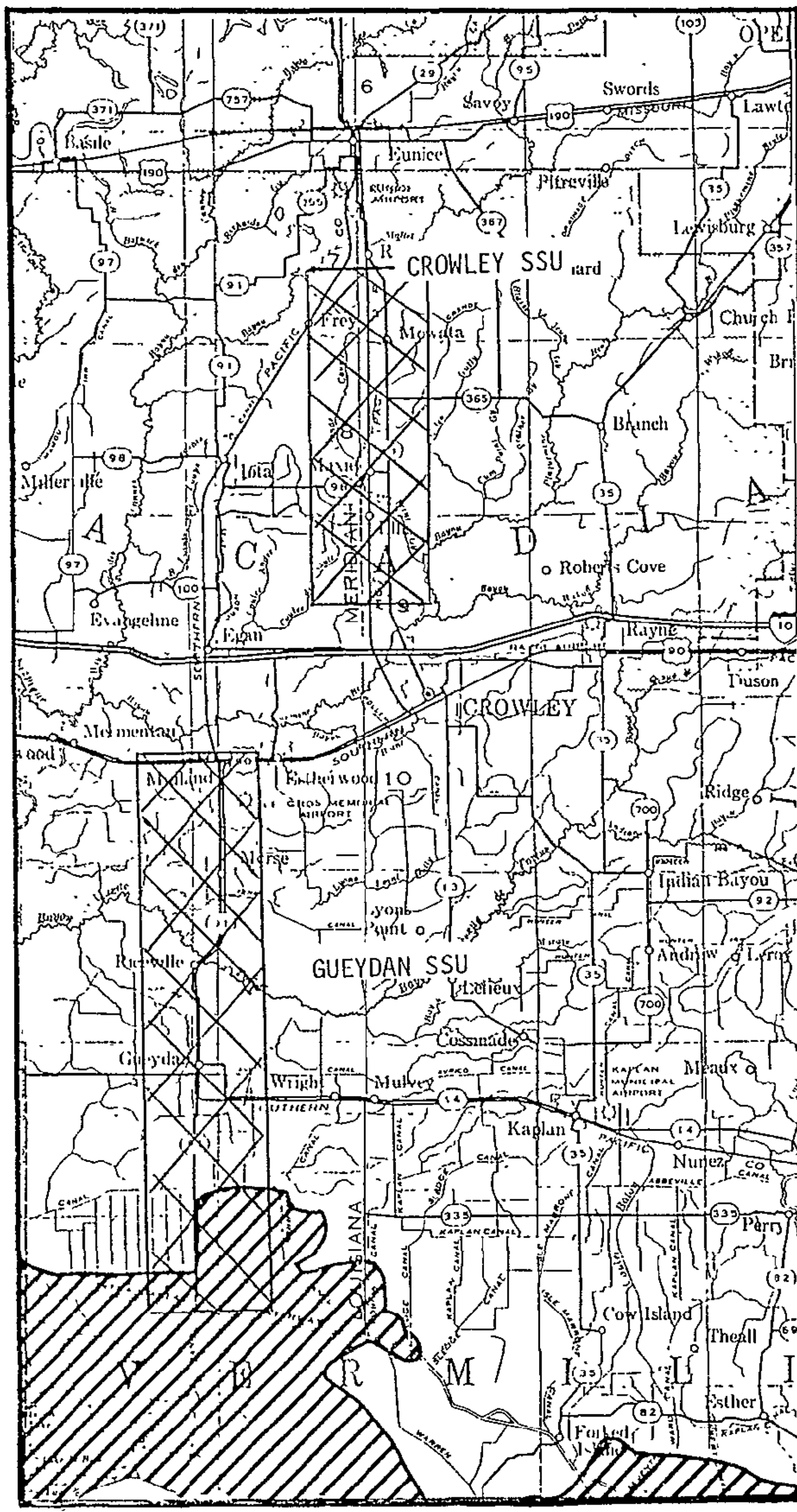


Figure 13. Louisiana Coastal Plain Test Region.



Primary Sample Unit

Figure 14. Primary and Secondary Sample Units, Louisiana Coastal Plain.

weevils, can also cause severe damage. Water management and soil preparation follow two basic patterns:

1. Fields are cultivated and leveled while dry and subsequently flooded, and
2. Fields are plowed and leveled while flooded.

Fields are then seeded by airplane and water is temporarily drained off when the seeds germinate to facilitate stable rooting. The fields are reflooded in two to three days, and kept at about four to eight inches of water depth until harvest time. Dry leveled fields are generally worked dry and drilled; the fields are flooded to a depth of about four to six inches until the seed germinates. After germination the water is drained for about two to three days and then returned to a depth of six to eight inches for the remainder of the season. Fields are drained prior to harvest and harvesting is done with a combine when fields are dry and rice kernels have between 9 and 16% moisture content. Average yields for the south central Louisiana area are about 32 barrels/acre (1 barrel = 113 pounds).

2.4.2.1.1 CROWLEY SSU

This SSU is located north of Crowley, Louisiana. It is a 4-by-12 mile block (124 square kilometers or 12,437 ha.) with its long axis oriented north-south. The soils are primarily silt or clay loams. Rice and soybeans are the major crop types in the Crowley subsample unit. Other crops include corn, sorghum, sweet potatoes, cotton, and pasture. In the Crowley test area dry leveling and drill seeding is the predominant method used in soil preparation and planting.

2.4.2.1.2 GUEYDAN SSU

This SSU is located south and west of Crowley, Louisiana. The major town situated in the area is Gueydan, Louisiana. The area is a 4-by-19 mile unit (197 square kilometers or 19,685 ha.). The soils range from the Midland type clay loams in the north to the mucky heavy clay loams of the marsh soils in the south. All are very poorly drained and the marsh soils are very high in organic material content. The major crop types are rice, soybeans, and pasture. The predominant soil preparation and planting practice in this unit is the working of the fields in flooded condition and rice seed sowing by airplane into the flooded fields. All other cultural practices are essentilly the same as in the Crowley area. Due to the slightly higher humidity, diseases are often more of a problem in this southern unit.

2.4.2.2 NORTHERN GREAT VALLEY PRIMARY TEST REGION

The Northern Great Valley Test Region is located in the northern half of the Central Valley of California. The climate of the area is Mediterranean to semi-continental. The winters are cool to cold with temperature ranges from -3° to 21°C (25° to 70°F). A majority of the precipitation occurs in the winter. The summers are warm and dry; temperatures range from 15° to over 38°C (60° to over 100°F) with some precipitation falling from sporadic thundershowers. The soils consist primarily of alluvial loamy sands. Over the entire area the crop type diversity is great, including rice, tomatoes, alfalfa, sugar beets, corn, sorghum, beans, peppers, wheat, barley, oats, safflower, orchard, vineyard, and pasture. The combination of clear, arid summer weather and the high crop diversity creates an excellent study area.

The majority of the rice is seeded by airplane into flooded fields. There are four major varieties used, Caloro, SC-S4, Calrose, and CS-M3. The planting season is generally from March to May. The fields are cultivated and leveled before flooding. Fertilizer is applied during the field preparation. The rice seed is then presoaked for 24 hours to soften the seed coat and initiate germination. The presoaked seed is then sown by an airplane onto flooded fields. Top dressing of fertilizer is applied in a manner similar to Louisiana practices. The total nitrogen applied is about 45 kg or 100 lbs./acre. Weeds are a problem in California including water hyacinth, bull rushes, and Johnson grass. Some root weevils are present and shrimp can be a problem. Otherwise few pests or diseases concern the California farmer. The fields are continuously flooded to a depth of six to eight inches from seeding to about two weeks prior to harvest time. The harvesting is done by combine when moisture content of the rice kernels drops to about 10 to 12%. The average yield for the California rice growing area is about 53 sacks/acre (1 sack = 45 kg or 100 lbs.).

2.4.2.2.1 <u>SUTTER SSU</u>

This site is located approximately 32 kilometers (20 miles) north and west of Sacramento, California. The test region is approximately 259 square kilometers (100 square miles) in size, and contains the town of Robbins. The soils consist of sandy clay loams, are deep and moderately to poorly drained, and are rich and well suited for all forms of agriculture.

The major crop types found in the Sutter area are rice, tomatoes, safflower, alfalfa, corn, sugar beets, orchards and vineyards, wheat and barley, and assorted row crops.

Rice fields are diked and flooded in March and seeded by airplane in April or May. There are four major varieties, two of which are early varieties and two late varieties. This mixture of varieties creates a complex mosaic of planting dates and phenological developments. The crop emerges from water in about four weeks and quickly forms 100% cover. The vegetative growth takes about two months, during which time fields are top dressed with nitrogen fertilizer by airplane. The crop forms heads and begins to mature 90 to 120 days after planting, depending on variety, and is harvested by combines when the grain has dried to 10 to 12% moisture content. Neither weeds nor disease present a serious problem.

2.4.2.2.2 MARYSVILLE SSU

The Marysville test site is located on the east side of the Sacramento Valley about five miles north and east of Marysville-Yuba City. It also contains a 259 square kilometer (100-square-mile block). This unit is located a little higher on the alluvial terrace and the soil types consist of coarser sandy loams than found in the Sutter area. These soils are moderately to well drained and are excellent agricultural soils.

The major crop types are rice, orchards, and extensive rangeland, with some alfalfa in the southeastern portion of the block. These crop types occupy fairly homogeneous blocks within the test site, corresponding roughly to distance from, and elevation above, the river bottom area.

2.4.2.2.3 MAXWELL SSU

This SSU is located on the west side of the Sacramento Valley just east of the Butte sink area of the Sacramento River. The soils are moderately

to poorly drained heavy clay loams. Some low-lying soil areas in the SSU are saline. The agriculture in the area is primarily rice. Numerous varieties are planted and some wild varieties are used. Other crops are tomatoes, milo and sugar beets in the lower portions of the SSU, and cereal grains in the foothill terraces in the western portion.

2.4.2.2.4 BUTTE SSU

Located in the northern portion of the Great Valley, this SSU is near the northern extent of the rice growing areas in California. The soils in the SSU are generally lighter and better drained than in the other SSUs. Other crops include cereal grains, tomatoes, and safflower but they are of minor importance during the rice growing season.

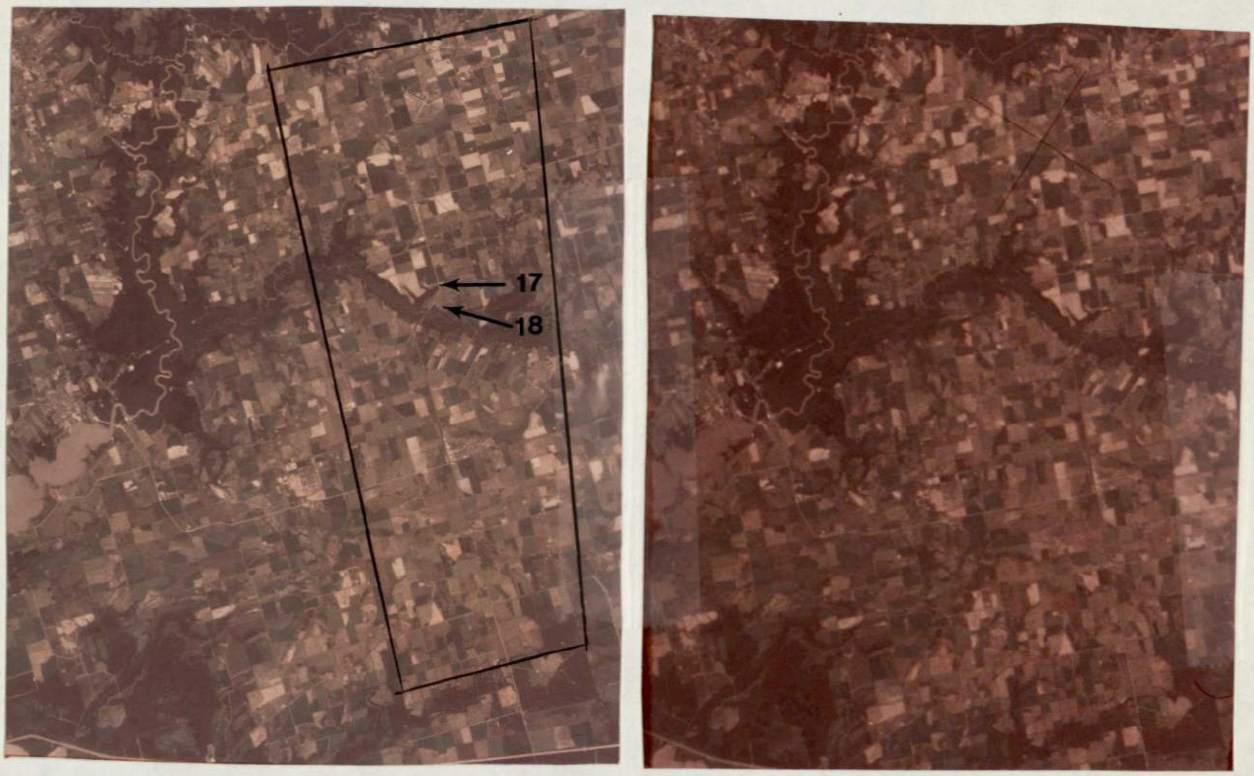
2.5 DATA RECEIVED AND DROPOUTS

2.5.1 EREP

A limited amount of EREP data were received for each of our test sites during the rice crop growing season because of both weather problems causing cloudiness over the test regions and because of changes in the data passes of the manned missions.

Typically, clouds form over the Louisiana coastal plain during the morning hours in summertime and persist with increasing accumulations throughout the day. These cloud layers obscure the ground scene and even the openings between clouds have high atmospheric moisture levels thus reducing reflected spectral energy.

Photographs from the Skylab-3 mission taken of Louisiana on August 4, 1973 (see Figures 15 and 16) were of high quality and were used for the photo interpretation tests conducted in this investigation (Figures 17 and 18 are oblique aerial photos of part of the same area). On September 16, 1973, the Skylab-3 crew photographed the southern test region (Gueydan SSU) of the Louisiana area. Although the photos were of high quality, the rice crop in the test sites had, for the most part, been harvested prior to that date.



Skylab Color S-190B

Skylab Color S-190A

Scale 1:327,000

Figure 15. These photos, taken August 4, 1973, of the Louisiana Coastal Plain rice test region, were used in the photo interpretation tests conducted in this investigation. Ground truth was obtained for a large number of fields in the test region outlined and fields were selected for testing within that area. Arrows indicate location of low-altitude aerial oblique photos in Figures 17 and 18. Note how rice crops were in various states of maturing and some had been harvested on this date.

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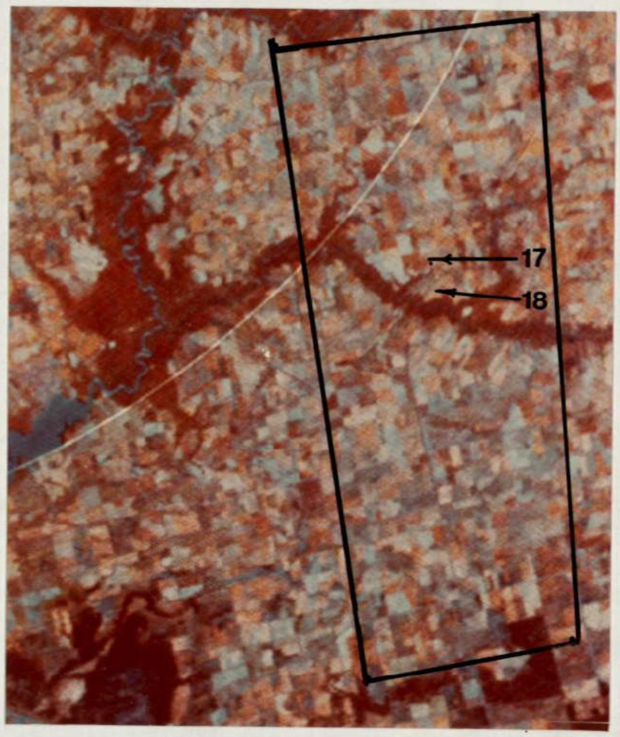


Skylab S-192 Color Composite Channels 1, 7 and 9
Scale 1:327,000

Figure 16. Color combined image of black-and-white bands from the multispectral scanner taken August 4, 1973, of the Louisiana Coastal Plain rice test region used in the photo interpretation tests conducted in this investigation. The rice crop in this area was in various stages of maturity at this date and it was difficult to identify crops on specific fields in the test region. Arrows indicate location of oblique photos in Figures 17 and 18.

Color Oblique Aerial Photo
August 11, 1973

Figure 17. Louisiana Coastal Plain Test Region showing unplanted area with some grass cover at left and green rice crop at right. Compare this photo with Figures 15 and 16.

Color Oblique Aerial Photo
August 11, 1973

Figure 18. Louisiana Coastal Plain rice crops showing harvested area on right and unharvested mature rice on left. These photos were used to document and extend ground truth and air checks. Compare this photo with Figures 15 and 16.

In the California rice test region, on the other hand, we received two dates of high quality coverage, June 3 and September 12, 1973 (see Figures 19, 20, and 21). Typically, the Northern Great Valley of California remains clear for extended periods thus permitting regular remote sensing coverage of the ground scene.

Tables 26 and 27 list the EREP and Skylab-support coverage obtained of the California and Louisiana test regions.

2.5.2 ERTS

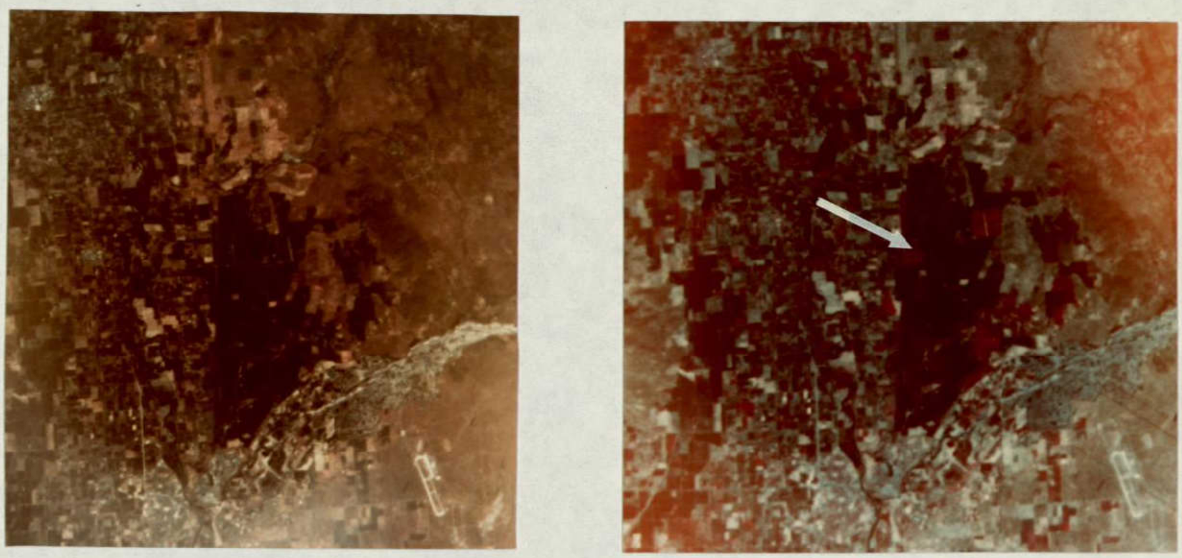
The ERTS coverage of the California and Louisiana test sites was similarly a function of weather conditions; i.e., we received an excellent series of coverages at 18-day intervals of the California test site (as noted in Table 28), and only limited coverage of the Louisiana test site (as noted in Table 29).

These data were very useful in our analysis of Skylab coverage as covered later in this report.

2.6 METHODS OF IMAGE ANALYSIS

2.6.1 EREP IMAGE ANALYSIS

Visual interpretation was performed on a comparative basis as each new batch of photographs was received from NASA and from our own project support flights. For those fields being analyzed

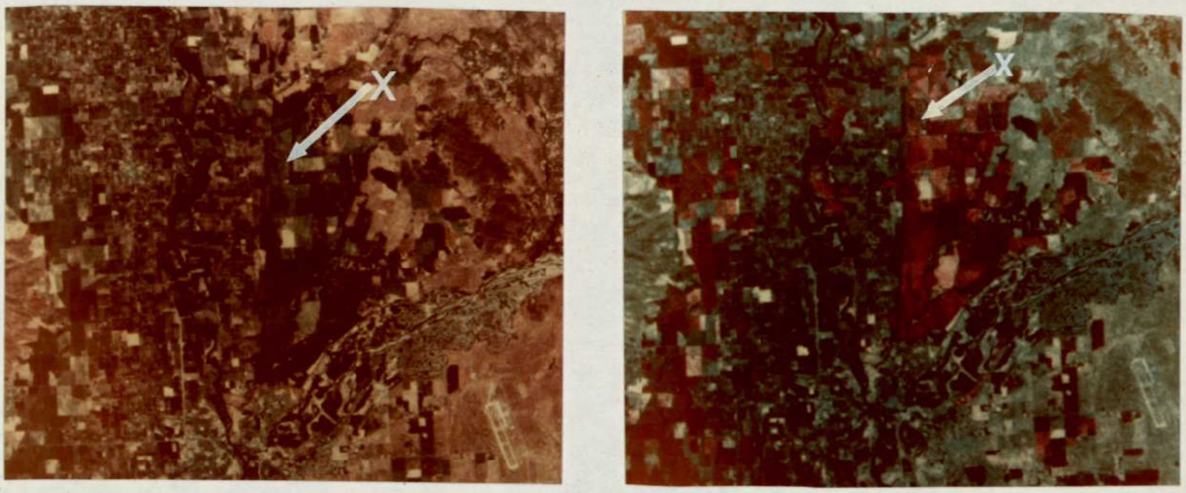


Color

Color IR

Scale 1:422,000

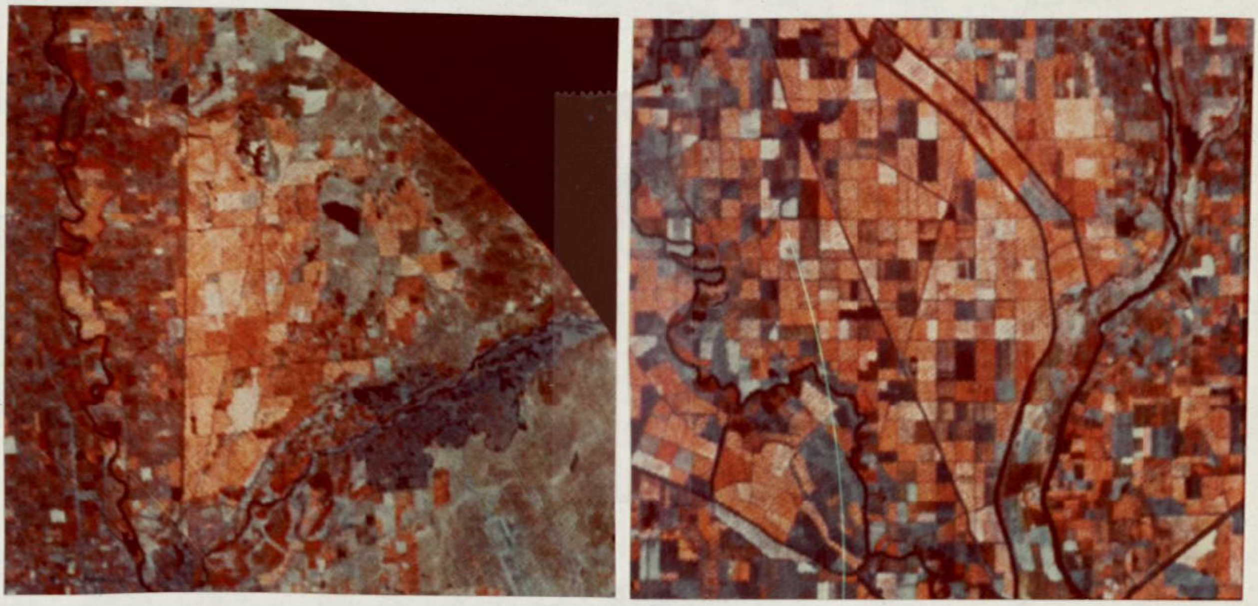
Figure 19. Skylab S-190A photos taken June 3, 1973, show Marysville, California test area rice fields dark green to black in color. The rice fields had been flooded and seeded, and in a few fields rice could be seen emerging above water, as noted by the reddish color of those fields on the color IR photo. (See arrow.)



Color Color IR

Scale 1:400,000

Figure 20. Skylab S-190A photos taken September 12, 1973, show Marysville test area rice fields as crop was maturing as noted by light green fields on color photo and pinkish fields on color infrared photo. Light tan fields had been harvested by the photo date. While total rice crop acreage on large tracts could be measured quite accurately on Skylab photos, such as these, it was not possible to evaluate crop vigor and detect stress conditions on such small-scale photography in the detail necessary for yield estimation. Aerial photos such as those appearing on the following pages are required for detailed yield estimation. Field at X is seen in following large-scale aerial photos and was one of several used in this study as a test field.



Marysville Test Area
Scale 1:310,500

Sutter Test Area
Scale 1:303,000

Skylab S-192 Color Composite Channels 1, 7 and 9

Figure 21. Color combined images of black-and-white bands from the multispectral scanner taken September 12, 1973, used in photo interpretation tests conducted in this investigation. Spectral fidelity was excellent, but because the crops are at late season status with some fields maturing and others already harvested, the crop identification accuracy was lower than it would have been had S-192 photos from an earlier mission been available. Photos taken about 30-45 days earlier would have provided a more uniform image of rice for identification purposes.

Table 26. Status of Skylab Imagery Availability for California Northern Great Valley Test Region

Image Type	Figure Number	Date	Condition or Interpretability of Test Region	Rice Calendar*
Skylab-2				
S-190A		June 3, 1973	Clear	c
Color	19			
Color IR	19			
Black-and-white				
Skylab-3				
S-190A		Sept. 12, 1973	Clear	f
Color	20			
Color IR	20			
Black-and-white				
S-190B		Sept. 12, 1973	Clear	f
Color				
S-192		Sept. 12, 1973	Clear, color composite of bands 1, 7 and 9	f
Color Composite	21			

* Legend

c = flooded fields with emergence of seedlings
f = maturing

Table 27. Status of Skylab Imagery Availability for Louisiana Coastal Plain Test Region

Image Type	Figure Number	Date	Condition or Interpretability of Test Region	Rice Calendar*
Skylab-3				
S-190A Color	15	Aug. 4, 1973	Clear	e
S-190A Color IR Black-and-white		Aug. 4, 1973	Clear, Transparency overexposed and un-useable in CIR	e
S-190B Color	15	Aug. 4, 1973	Clear	e
S-192 Color Com-posite	16	Aug. 4, 1973	Clear, color com-posite of bands 1, 7 and 9.	e
Skylab Support Color and Color IR		Aug. 11, 1973	2% Cloud Cover, obscured area	e
Skylab-3		Sept. 16, 1973	Clear, Coverage of Gueydan SSU only.	f,g
S-190A Color Color IR Black-and-white				

*Legend:

e = heading
f = maturing
g = harvest

Table 28. Status of Imagery Availability for Northern Great Valley Test Region

Imagery Type	Figure Number	Date	Condition or Interpretability	Rice Calendar*
ERTS		26 Jul '72	Excellent	
		17 Mar '73	Excellent	
		4 Apr '73	Excellent	
		22 Apr '73	Excellent; color composite received	a
		10 May '73	Excellent; color composite received	b
		28 May '73	Excellent; color composite received	b,c
		15 Jun '73	Excellent; color composite received	c
		3 Jul '73	Excellent; color composite received	d
		21 Jul '73	Excellent; color composite received	d
		8 Aug '73	Excellent; color composite received	e
		26 Aug '73	Excellent; color composite received	e
		13 Sep '73	Excellent; color composite received	f
Aircraft Support (NASA)		12 May '73	Some overexposed	b
		3 Jun '73	Excellent	c
		5 Jul '73	Excellent	d
		12 Sep '73	Excellent	f
		10 Oct '73	Excellent	g,h
Large Scale (EarthSat)		7 May '73	Complete coverage of test areas	b
		14 Jun '73		c
		10 Jul '73		d
		28,29 Aug '73		e
		14 Sep '73		f

* Legend
- a = Field preparation
- b = Flooded fields and rice sowing
- c = Flooded fields with emergence of seedlings
- d = Vegetative growth
- e = Heading
- f = Maturing
- g = Harvest
- h = Stubble conditions

Table 29. Status of Imagery Availability for Louisiana Coastal Plain Test Region

Imagery Type	Figure Number	Date	Condition or Interpretability	Rice Calendar*
ERTS-1		13 Mar '73	100% cloud cover	
		31 Mar '73	Clear; color composite received	a
		18 Apr '73	100% cloud cover	b
		24 May '73	30 to 40% cloud cover; color composite received	c
		29 Jun '73	20% cloud cover; test site obscured	d
		22 Aug '73	Clear; color composite received	f
		9 Sep '73	80% cloud cover	g
		27 Sep '73	50% cloud cover	g,h
		15 Oct '73	80% cloud cover	h
Aircraft Support (NASA)		11 Aug '73	2% cloud cover	e
Large Scale (EarthSat)		31 Mar '73	Complete coverage of test region	a
		3 Jun '73		b,c
		29 Jun '73		d
		28 Jul '73		e
	17,18	11,14 Aug '73		f
		19 Sep '73		f,g

*Legend:

a = Field preparation
b = Flooded fields and rice sowing
c = Flooded fields with emergence of seedlings
d = Vegetative growth
e = Heading
f = Maturing
g = Harvest
h = Stubble conditions

in the SSUs, we were able to detect on large-scale photos plant growth characteristics ranging from very vigorous to poor vigor and missing plants. We then compared the usefulness of each image type (spectral band, date, system and scale) for detecting the crop condition in question and selected image examples which would be used in a formal photo interpretation testing phase to be conducted after all data had been acquired.

Where multidate photos were obtained, the detectability of desired features and conditions was evaluated on the various dates of coverage. Very limited multidate coverage was provided of our rice test areas by EREP systems, but ERTS-1 multidate coverage provided an excellent opportunity to compare multidate images both visually and in an additive color viewer.

Formal photo interpreter testing was conducted on a selected set of photos using test subjects from classes in photo interpretation at the University of California. Interpreters were instructed to identify the crop type on a series of fields on each of several photographs (multidate and multiband) by comparing fields identified by number only with fields (training sets) where true identity of crop type was given (Appendix B). The responses of the interpreters were scored and an analysis made of errors of commission and omission in crop identification. The results of the tests are given in Section 2.7, Quatitative Test Results and Analysis.

2.6.2 AIRCRAFT IMAGE ANALYSIS

As noted above, the aircraft photography served as a means by which ground truth regarding crop identity, crop acreage and crop vigor factors (pest and weed problems and effects of natural conditions) could be assessed accurately.

In most cases only the large-scale vertical and oblique photos taken by project staff from the company operated aircraft were useful for determining actual identification of ground conditions and crop types. The high-flight support photos provided by NASA were helpful to a limited degree for plotting field boundaries and general crop type, but these data were not satisfactory for determining actual crop identity needed for ground truth to be used in the photo interpretation testing phase.

A problem was encountered because the high-flight photos of Louisiana taken by NASA did not cover completely the desired test region and could not be used in the testing phase. We were given excellent high-flight support photography of the California test region by the NASA U-2 aircraft from Ames Research Center.

For crop stress and vigor evaluation, and for detecting the presence of weed infestations or lodging, we utilized the aircraft photos to locate such problems initially and followed-up by evaluating the detectability of those conditions on the high-flight and space photos. We were then able to extend our crop condition interpretations to surrounding fields where we did not have verification of the condition by large-scale aerial photos. In some cases we requested confirmation of our interpretations from cooperating growers.

2.6.3 GROUND DATA COLLECTION PROCEDURES

2.6.3.1 LARGE-SCALE AERIAL PHOTOGRAPHY

Throughout the season large-scale aerial phtography was acquired by EarthSat personnel. The aircraft used was a Cessna 206 equipped for high altitude (up to 30,000 feet) operation and multiband photography. The purpose of this large-scale photography was to monitor selected individual fields on a high resolution basis and to cover an entire SSU at a lower resolution, smaller scale.

Two formats were used. The high resolution imagery at an approximate scale of 1:3,000 was acquired using a K-17 9" x 9" camera equipped with a 30.48mm (12 inch) focal length lens. For the complete SSU coverage at smaller scales (1:20,000) Hasselblad 70mm cameras equipped with 80mm focal length lenses were used. Two emulsions, Ektachrome MS (2448) (conventional color) and infrared Ektachrome (2443) (color infrared), were utilized in both formats. Examples of this imagery and corresponding NASA support photos are shown in Figures 22 through 25 and 27 through 29.

In addition to the vertical photography, oblique 35mm color and color infrared photography was obtained during each mission. These photos were taken to document field conditions or cultural practices. Examples of this type of photography are shown in Figures 17, 18, and 26.

Acquisition of the large-scale vertical and oblique photography was scheduled to occur at critical periods throughout the rice growing season. These critical periods were generally defined by changes in phenology (crop calendar) and included:

Color Aerial Photo
Scale 1:42,000

Color IR Skylab Support Photo
Scale 1:82,500

Figure 22. Photograph at left is an aerial photo taken on May 7, 1973, while Marysville rice fields were being flooded prior to seeding of rice from low-flying aircraft. Note tan fields were bare, dry soil in fields that had been prepared for flooding. Field at lower left shows the effects of sunglare on standing water. Photograph at right is from a Skylab support mission taken June 11, 1973 on color IR film after the rice fields became covered by standing water and newly emerged rice plants as evidenced by the red colored fields. Earlier planted fields are completely covered with vegetation, while later planted fields appear mottled with black (standing water). Note field at X on other Marysville photos.

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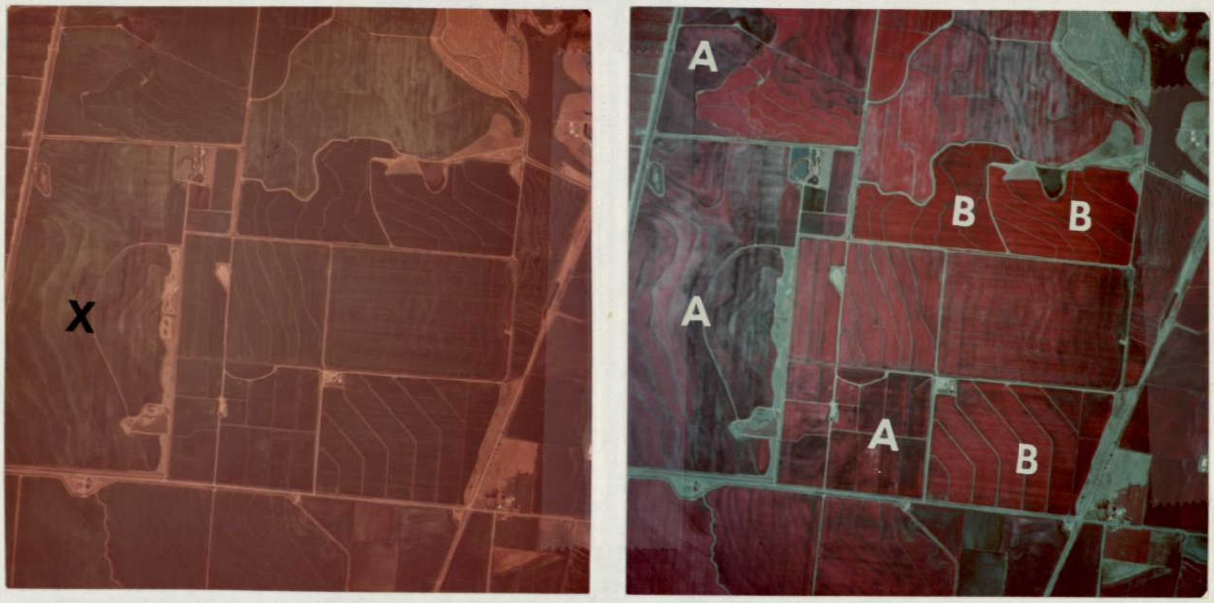
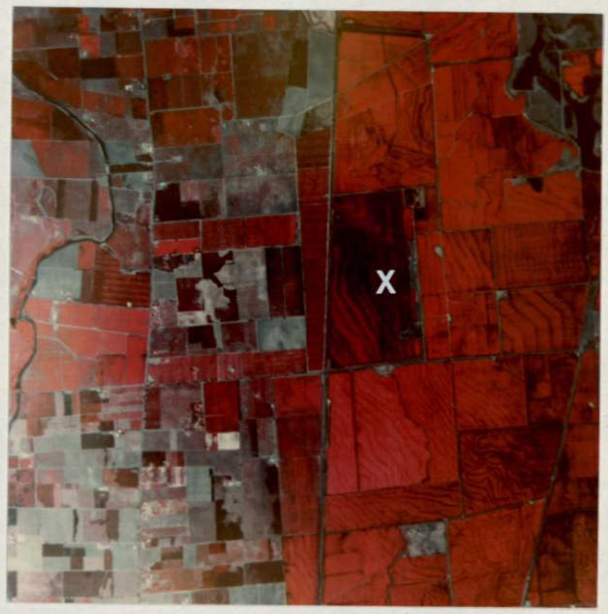


Color Color IR

Aerial Photos, Scale 1:45,000

Figure 23. Photographs of Marysville rice test area taken June 15, 1973, showing the advantages of using color infrared film for evaluating rice crop establishment over color film. The fact that there is a red/blue contrast between rice and water on color IR film enhances the visibility of rice over the green/bluish-green contrast of the color photo. In this case it is possible to detect several rice fields with reduced vigor and thin stands such as the ones seen at A that contrast with the lush growth of the fields with high quality stands of rice seen at B. Field at X yielded 5100 lbs. per acre of dry rice according to data provided by the cooperating farmer.



Color IR Skylab Support Photo
Scale 1:126,500

Figure 24. Photograph of Marysville rice test area taken July 5, 1973, showing field at X with sparse rice stand as compared to surrounding fields. At this photo date our interpretation indicated a reduced yield would probably result because of this condition. In this case the farmer did not report any significant problem with the crop. In comparison with surrounding rice fields it is obvious that the crop is delayed in achieving full ground cover.

Color Color IR

Aerial Photos, Scale 1:42,000

Figure 25. Photographs of Marysville rice test area taken July 10, 1973, showing greater detail in rice fields than is visible on previous support photos taken from high altitude (65,000') NASA aircraft. Note the greater visibility of both high and low vigor areas on color IR photo versus color. Particularly in field at X the uneven crop cover is readily visible on color IR photo.

Color

Color IR

Figure 26. Oblique photos such as these taken on August 31, 1973, of the Marysville test area are used to document conditions in selected areas. Only general interpretation is done on these photos although large-scale oblique photos taken from low altitudes are used to provide ground truth at selected locations. Compare field at X with other Marysville photos.

August 29, 1973 September 13, 1973

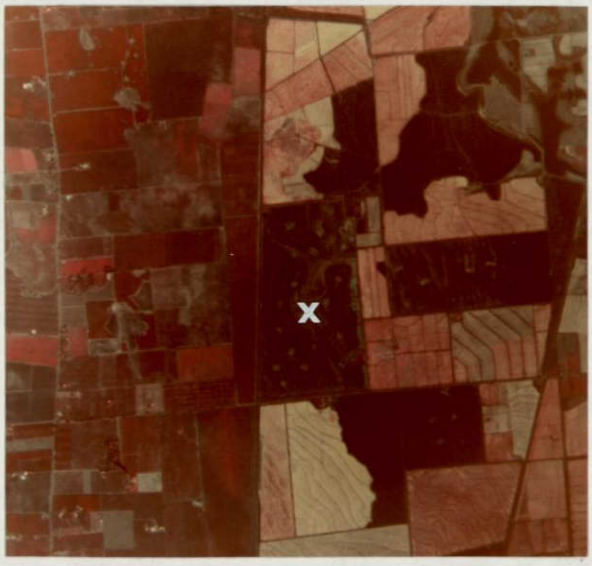
Color IR Aerial Photos, Scale 1:32,000

Figure 27. Photographs taken about two weeks apart of the Marysville test area show the changes in appearance of rice fields as crop matures. Photo at right shows the field at X is maturing unevenly and the interpreter might be led to believe erroneously that there are severe growth problems in that field as evidenced by the greyish colored areas. Photo at left reveals only relatively minor growth problems and some lodging (light pink areas) at arrows. Compare with previous photos to assess location of crop vigor problem areas (early maturing at right side of field).

Color Color IR

Skylab Support Photos, Scale 1:73,500

Figure 28. Photographs of the Marysville test area taken September 12, 1973, show variable maturing rice fields on both color and color IR film. These photos are very useful for later season evaluation of crop growth and status of critical events (maturing and harvest) where more general information is needed. Detailed information on crop conditions can be obtained from aerial photos such as the one in Figure 27 taken one day later. Note linear patterns of rice coloration in field at X caused by uneven application of fertilizer from aircraft.



Color IR Aerial Photo
Scale 1:76,000

Figure 29. Photograph of Marysville rice test area taken October 10, 1973, shows post harvest appearance of fields. Black areas have been harvested and the stubble burned, in many cases, in preparation for flooding and use for duck hunting. Note small light toned patches in field X which mark duck blinds installed for hunting purposes.

(a) Field preparation

(b) Flooded fields and rice sowing

(c) Flooded fields with emergence of seedlings

(d) Vegetative growth

(e) Heading

(f) Maturation

(g) Harvest

(h) Stubble conditions.

Each of these discrete periods can be recognized by crop characteristics and appearances such as color, texture and plant density, and cultural practices such as plowing, flooding, and harvesting. The timing of each of these conditions relative to a nominal crop calendar can have a profound effect on yield and it is exceedingly important to document each when it occurs.

The initial intent of the large-scale aerial photography was fivefold. The first was to provide highly accurate measurements of actual rice cropped acreages. Basic to any prediction of yield of any crop on a regional basis is the ability to determine the actual cropped acreages. This acreage would be estimated for each SSU by determining the photo scale, delineating the actual rice cropped area on the photos, then converting to actual rice cropped acreages on the ground. In this way yield predictions based on cropped acreages could be determined for the SSU and expanded to the rice crop region. In actuality it was found that the NASA-provided aircraft support photography (the RC-10 24" focal length

9"x18" format at a scale of 1:30,000) was optimal in terms of required resolution and area of coverage.

The large-scale photography was also used to determine specific field conditions. On the smaller scale photography (1:20,000 and 1:30,000), the identification of crop type and general field conditions (e.g., flooded, fully vegetated, harvested, etc.) was possible. However, for the yield prediction procedure specific field conditions such as relative area of emergence, green headed, etc. were required. The large-scale 9"x9" photography was designed to yield these types of information.

In order to assess accurately the quantitative impact of yield-affecting factors, it is necessary to determine the surface area affected by the factor. For example, if blast disease was observed in a field, it would be necessary to know what percentage of the field is affected in order to adjust the yield for the field. It was determined that the order of accuracy needed for these types of assessments was not available from the smaller scale imagery, thus the use of the higher resolution, larger scale.

The improved resolution characteristics of the large-scale photography also made possible the extension of the area of "ground data collection." The resolution of the large-scale photography usually allowed assessment of such factors as green heading, leaf color, plant density, etc., the types of information being gathered by EarthSat field crews and cooperating farmers. In fact, the large-scale photographs allowed better assessment of entire field condition than ground observations due to the overhead synoptic view. Given the constraints of time and budget typical of most crop survey projects, the large-scale aerial photography greatly extended the areas where detailed crop information was available.

The last function of the large-scale photography, both vertical and oblique, was to record, for reference and illustrative purposes, the appearance of the yield-affecting factors for Skylab comparison.

2.6.3.2 GROUND DATA COLLECTION

Ground data collection was accomplished by two different methods. One method utilized farmer cooperation and the other involved EarthSat personnel.

The individual fields monitored throughout the season with the large-scale aerial photography were generally those operated by cooperating farmers. These farmers were provided with standard data sheets which asked for the types of data necessary for our evaluation of the actual field conditions. The sheets were pertinent to each of the two study areas, Louisiana and California, asking only for data necessary. The cooperators were asked to fill out the data sheets and return them at the end of the rice season. Examples of the data sheets are presented on two following pages.

EarthSat personnel were also sent into the field at appropriate times to spot check and describe field conditions and record them with ground photographs. Not as obvious but probably most important was the interaction of the EarthSat field people and the rice farmers. Through conversations with the farmers a great amount of background information was learned which was useful in establishing crop calendars and describing crop appearance. The field personnel were also helpful in image analysis for many of the interpretation tasks and the information they derived from these conversations was directly applicable in guiding their interpretive activities. For example, in Louisiana lodging, even late season

Field Data Sheets: For each field please record the following types of data.

Field no.: 5.—
Date of planting: 5-20-73
No. of acres: 220
Preparation method: plow disk float.

Date of seeding: 5-20-73
Date of germination (if observed): 5-30-73
Variety planted: Caloro
Method of seeding: air

Application of fertilizer

Type	Date	Concentration
N	5-15-73	100 lb
P	5-15-73	100 lb

Application of herbicides or fungicides

Type	Date	Concentrations	Method	Results
Molinate -	5-30-73	60 lb granules	air	satisfactory
MCP	7.-5-13	16 oz	air	satisfactory

Water fluctuations

Type of fluctuation	Date	Water condition (clear, muddy)
Constant flood	5-19-73	Clear

Weed problems

Type	Date	Treatment	% of field affected
Watergrass	5-15-73	Molinate	100
Broadleaf	7-5-73	MCP	100

Diseases

Type	Date of occurrence	% of field affected	Treatment	Results

Lodging

When occurred	Severity (% of field down)
10-10-73	86 %

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Harvest date: 10-15-73
Bulk weight: 5200 pr acre
Milling percentages: fair -

lodging, is a problem due to the high moisture availability (very conducive to fungi and molds) and generally reduces yield significantly; in California, where it is drier, late season lodging is not as severe a problem and may even be indicative of a higher yield (the heavier heads being more susceptible to blow down). Yet on the data sheets both the Louisiana and California farmers merely indicate the presence and percentage of lodged grain. Without the background information specific to each area, serious interpretation errors could occur.

Effort was made to include fifteen to twenty fields, totaling 1,000 to 1,500 acreas, in each of the four SSUs. This figure was chosen because it seemed an adequate and representative sample for the entire SSU. In addition, it was arranged for the acreages to be dispersed among as many farmers as possible so that a representative cross section of cultural practices could be analyzed. Along with a purposeful dispersal of acreages among farmers, it was hoped that there would be a representative pattern of fields so that the area was covered uniformly.

Generally, the farmer response was good in both Louisiana and California. An exception was in the Butte SSU. Communication problems with the County Extension Agent were the basic reason. Otherwise, the farmers who responded and eventually cooperated showed little unwillingness to release their records and were extremely eager to share in the knowledge gained. A point relative to this is the type of farmers who are generally willing to cooperate. These farmers are generally the better ones, most proud of their farming methods and yields and therefore very willing to share information about them. The farmer who will not cooperate seemed to be a little less able with perhaps more cultural problems and lower yields.

This characteristic creates a ground data problem because it essentially biased our sample toward the good cultural practices, and away from the desirable objective, the study of yield-limiting factors.

A problem of actual data submittal was also encountered. In many cases even with repeated follow-up by project staff the ground data needed for progress in the study was received five to six months after the end of the season. This time lag not only slowed project advance, but also compounded the problem of relating ground conditions to photographs of image appearances. With data being received months after the condition had come and gone, it was nearly impossible to reconstruct or verify some of the data.

Despite the problems, the ground data collection program was successful in terms of farmer participation, readout, and quality of data collected.

2.6.4 IMAGERY AVAILABLE FOR STUDY

The imagery available for the study (including Skylab, NASA aircraft support, and EarthSat large scale) is indicated in Tables 28 and 29. Perusal of these tables underlines the major problem in this study, the limited amount of satellite and NASA/support coverage in Louisiana during the rice season, combined with a major effort in acquiring large-scale support photography. (See accompanying photo examples.)

2.6.5 PROPOSED PROCEDURE

In general terms, the procedure to be used in producing acceptable estimates of yield of rice and other grain crops is as follows (see Figure 30).

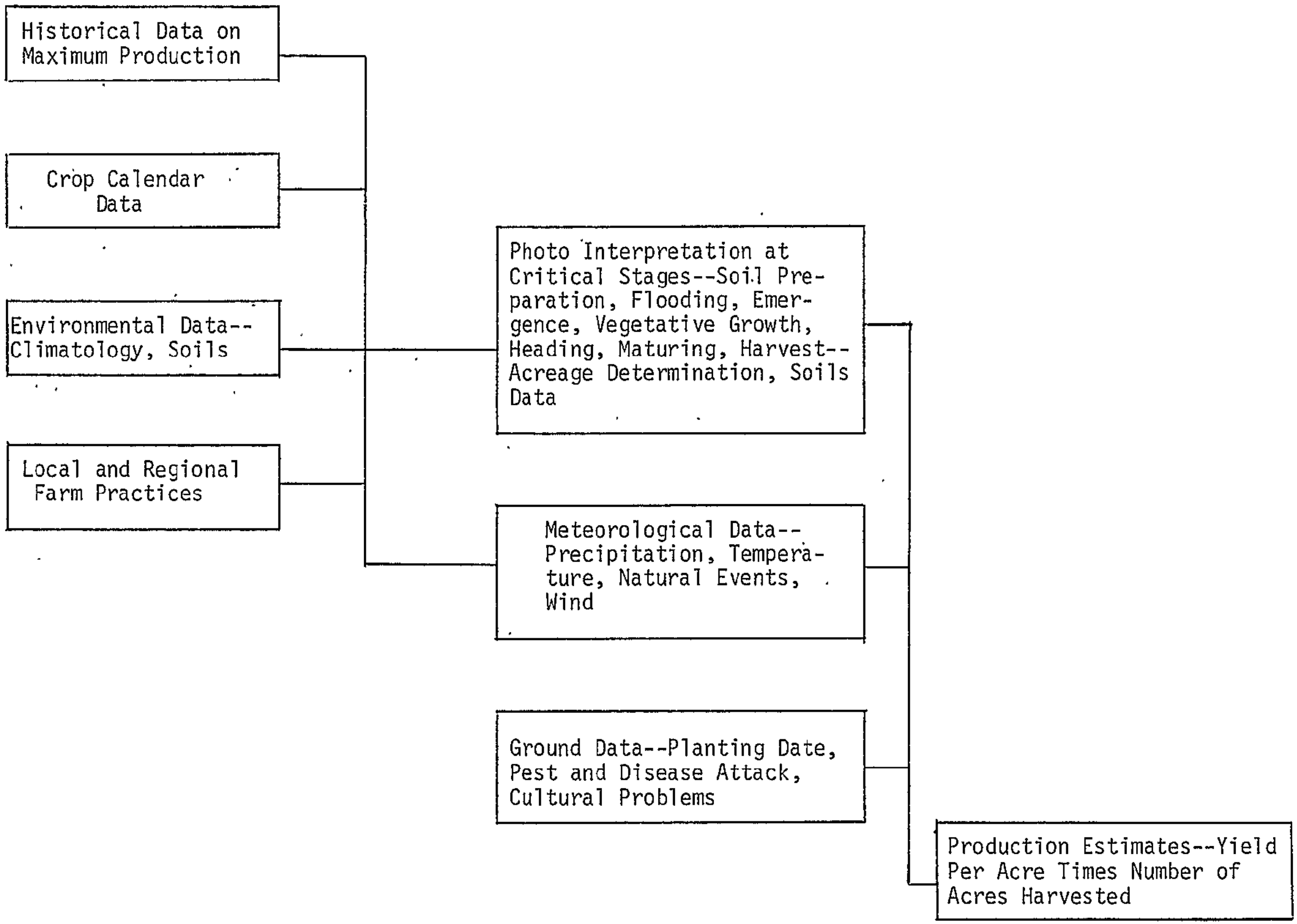

Figure 30. Flow Diagram for Rice Yield Information.

a. By image interpretation or historical reference data, delineate the boundaries of the major crop growing regions and determine their areas. Develop a suitable sampling scheme to monitor "indicator" areas at each of the critical periods described in the next section for the major crop areas.

b. Prepare reference materials and photo interpretation keys and instruct photo interpreters in the image characteristics and crop signatures that are to be used for interpreting space and aerial photos.

c. Obtain color infrared* photos at four or five critical periods during the growth of the grain crop coinciding with: (1) soil preparation prior to planting,** (2) full cover of ground (water) by plant foliage, (3) full foliage growth immediately prior to emergence of fruiting bodies, (4) mature green crop immediately prior to yellowing and (5) optional coverage immediately prior to harvest in the event serious crop damage has occurred by weather factors since the previous coverage.

d. By photo interpretation determine when an anomaly (area of reduced plant vigor) appeared in a particular field and judge the identity, extent and severity of that anomaly.

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*Other film/filter combinations are less useful and may not provide needed image contrast.

**As noted earlier for rice crop identification photographs taken when fields are flooded but rice does not yet cover water are highly useful and should be added to this list of photo coverage dates.

This determination is made by searching for non-uniform features within a given field such as color variability, texture differences, and uneven plant density (e.g., soil deficiency causes chlorosis and stunting, appears early and does not spread; disease causes loss of vigor, stunting and will spread from a mid-season start). Area of crop and of anomalous images within crop fields are usually determinable by visual methods, digital scanning techniques or electronic image enhancement devices.

e. Using the best estimate of maximum potential yield for the rice crop being grown in the given region (i.e., assuming all crop production factors were optimum and thus no yield reduction occurred), compile yield estimates at each photo date by a subtractive process from the maximum potential yield based on photo interpretation information. Thus, at each date of photography an accurate estimate would be made of the yield from the region under consideration thereby assuming that all remaining factors and growth conditions would be optimum. As each phase of photography is interpreted, a new yield estimate would be made by the subtractive method reducing the previous estimate by only those factors which were newly visible or became more severe. (See Appendix D.)

2.7 QUANTITATIVE TEST RESULTS AND ANALYSIS

2.7.1 NORTHERN GREAT VALLEY TEST REGION ALONE

2.7.1.1 TEST 1 - CROP IDENTIFICATION, LATE SUMMER SEASONAL STATE

Interpretation results from each interpreter response sheet were scored and tabulated in matrix form to indicate the correct responses as well as the occurrence of commission and omission errors (Figure 31). For Test 1, a total of 60 responses occupy each such matrix (6 categories x 10 test items per category for each image type). Results from Tests 2 and 3 were also tabulated in a similar fashion (Appendix E).

The tabulated data (correct responses) were subjected to a two-way analysis of variance. Tests of significance were performed for the main effects (image type and crop category) and interactions, and all were found to be very highly significant.

Results of pairwise comparisons across the image type effects using Tukey's method are presented in Table 30. Each entry in this table represents the mean number of correct responses (maximum possible = 10) for each crop category from each image type, based on the 400 responses obtained collectively from the 40 students who took this test.

For a given crop category (e.g., within a column on Table 30), the starred entries fall with a confidence interval of ± 0.5 response and are significantly different from the other image types. All other entries in that column fall outside this interval. Within the orchard category, for example, the ERTS color composite and EREP S-190A color infrared image form an image set which is significantly different from the others and best for identifying orchard crops.

AGRICULTURE TEST RESULTS

Name Menashe

Group-Section I - A

Image Skylab 190A CIR

Ground Truth

PI Calls	R	O	A	F	G	X
R	9		2			1
O		4	1			
A	1	2	5			2
F		1		9		1
G				1	10	
X		3	2			6
	10	10	10	10	10	10

Figure 31. Sample response matrix for Test 1. Correct responses appear in the outlined diagonal boxes. This interpreter achieved 71.7% correct (43/60) for the Skylab 190A CIR image. He made very accurate responses for 3 categories (rice, fallow, and dryland pasture) and was less accurate in his interpretation of orchard, alfalfa, and other agricultural crops.

Table 30. Analysis of Test 1 Data
(Crop Identification Test, Late Summer Seasonal State)
by Means of Tukey's Method of Pairwise Comparison

Entries in the table below are mean number of correct responses per interpreter. Starred entries within a column fall within a confidence interval of ± 0.5 response and form an image class which is significantly different from the unstarred entries, and are therefore best for the interpretation of the crop category which heads that column. The far right column contains the average for all categories. Note that the ERTS color composite and EREP 190A Color IR images are significantly different from the other image types and, therefore, better for overall interpretative purposes. If no interpretation errors have been made by any of the 40 students, all entries in this table would contain the figure "10.0."

		CROP CATEGORY						
		Rice	Orchard	Alfalfa	Fallow	Dryland Pasture	Other Agric.	Average for All Catagories
IMAGE TYPE	ERTS-5	4.7	4.5	5.8	5.1	*9.2	3.8	5.5
	ERTS-7	6.9	7.4	*7.8	3.8	7.0	5.6	6.4
	ERTS Color Composite	7.1	*7.9	5.4	*8.1	*9.4	*6.8	*7.4
	EREP 190A B/W Red	5.9	4.8	4.6	6.8	8.7	5.5	6.0
	EREP 190A B/W IR	7.4	6.5	*7.7	4.3	7.4	6.4	6.6
	EREP 190A Color	*8.3	7.1	4.6	6.2	*9.0	5.1	6.7
	EREP 190A Color IR	7.3	*8.0	5.8	*7.8	*8.9	*7.2	*7.5
	EREP 190B Color	7.6	7.3	4.8	6.8	8.6	5.8	6.8

Overall identification accuracy is also presented in Table 30 for Test 1. Overall results for the ERTS color composite and Skylab S-190A images are significantly different from the other image types, but there is no difference between them. The set of eight image types is ranked in the following manner with no statistical significance assigned to the ranking (extracted from Table 30):

Image Type	Overall Average Correct Responses (all crop categories)1/
EREP S-190A Color IR	7.5
ERTS Color Composite	7.4
EREP S-190B Color	6.8
EREP S-190A Color	6.7
EREP S-190A B/W IR	6.6
ERTS Band 7	6.4
EREP S-190A B/W Red	6.0
ERTS Band 5	5.5

1/ Maximum possible = 10

Commission errors were also analyzed using a two-way analysis of variance. Tests of significance were performed for the main effects (image type and crop category) and interactions, and all were found to be very highly significant. Pairwise comparisons were made using Tukey's method. The image type(s) which formed a group that was significantly different from the others (lowest commission error) are listed in Table 31.

From a standpoint of commission error, Table 31 suggests that the ERTS color composite might be favored over the EREP S-190A color IR image. This conclusion is indicated because the ERTS color composite appears four times in Table 31, while the S-190A color IR image appears only twice.

Table 31. Analysis of Test 1 Data
(Crop Identification Test)
Ranking by Image Types by Commission Error

For each of the crop categories listed below, the image type(s) are given which form a group that is significantly different from all others in terms of commission error (using Tukey's method of pairwise comparison). These image types are those for which commission errors are lowest.

Crop Category	Image Type
Rice	ERTS Band 7 EREP S-190A B/W IR
Orchard	ERTS Color Composite EREP S-190A Color IR
Alfalfa	EREP S-190A Color ERTS Band 5 EREP S-190A B/W IR
Fallow	ERTS Color Composite
Dryland Pasture	ERTS Color Composite
Other Agricultural Crops	ERTS Color Composite EREP S-190A Color IR

2.7.1.2 TEST 2 - CROP IDENTIFICATION, LATE SPRING SEASONAL STATE

The objectives and format of Test 2 were parallel to Test 1 with the following exceptions:

1) Imagery for the late spring seasonal state was used instead of late summer seasonal state.
2) Skylab EREP S-190B color imagery was not acquired at this date and therefore not tested.
3) The Sutter Test Site was not imaged by Skylab at this date, and the number of test items common to both tests (in the Marysville Test Site) was therefore reduced from 60 to 32.
4) Only 10 students were used for this test.

Test responses were normalized and the results expressed on a basis of 10 test items per category. In this way, results of this test can be compared with Test 1.

The tabulated data were subjected to a two-way analysis of variance. Tests of significance were performed for the main effects (image type and crop category) and interactions, and all were found to be very highly significant.

Results of pairwise comparisons across the image type effects using Tukey's method are tabulated in Table 32. Each entry in this table represents the mean number of correct responses (normalized to a maximum possible of 10) for each crop category from each image type.

For a given crop category (e.g., within a column on Table 32), the starred entries fall within a confidence interval of $\pm$ 3.2 responses and are significantly different from the other image types. All other entries in that column fall outside this interval.

Table 32. Analysis of Test 2 Data
(Crop Identification Test, Late Spring Seasonal State)
by Means of Tukey's Method of Pairwise Comparison

Entries in the table below are mean number of correct responses per interpreter. Starred entries within a column fall within a confidence interval of ± 3.2 responses and for an image class which is significantly different from the unstarred entires, and are therefore best for the interpretation of the crop category which heads that column. The far right column contains the average for all categories. Note that the EREP S-190A Color and Color IR images are significantly different from the other image types and, therefore, better for overall interpretative purposes. If no interpretation errors have been made by any of the 10 students, all entries in this table would contain the figure "10.0."

	CROP CATEGORY						
IMAGE TYPE	Rice	Orchard	Alfalfa	Fallow	Dryland Pasture	Other Agric.	Average for All Catagories
ERTS-5	*7.3	5.3	*6.0	*5.7	*6.9	*4.0	5.9
ERTS-7	*10.0	6.4	*3.7	4.0	*7.9	*1.7	5.6
ERTS Color Composite	*10.0	6.0	*3.7	*7.7	*8.0	*1.3	6.1
EREP S-190A B/W Red	7.2	*7.4	*5.0	*7.3	5.1	*2.7	5.8
EREP S-190A B/W IR	*9.5	5.3	*5.5	3.0	5.6	*3.7	5.4
EREP S-190A Color	*9.5	*8.7	*4.7	*10.0	*6.9	*2.7	*7.1
EREP S-190A Color IR	*10.0	*8.1	*3.8	*7.3	*6.1	*6.7	*7.0

Overall identification accuracy is also presented in Table 32 for Test 2. Overall results for the EREP S-190A color and EREP S-190A color IR images are significantly different from the other image types, but there is no difference between them. The set of seven image types (EREP S-190B color image not tested) is ranked in the following manner (extracted from Table 32):

Image Type	Overall Average Correct Responses (all crop categories)1/
EREP S-190A Color	7.1
EREP S-190A Color IR	7.0
ERTS Color Composite	6.1
ERTS Band 5	5.9
EREP S-190A B/W Red	5.8
ERTS Band 7	5.6
EREP S-190A B/W IR	5.4

1/ Maximum possible = 10

The relative interpretability of the various crop categories at the two seasonal states--late summer (Test 1) and late spring (Test 2)--is perhaps best determined by comparing the test results for the EREP S-190A color IR image. This image ranked high in both tests and in both tests was contained in the group of two images that was significantly different from the other test images. Those results, extracted from Table 30 and 32, are presented here (expressed as mean number of correct responses, maximum possible of 10 in each category):

Test	Crop Category						
	Rice	Orchard	Alfalfa	Fallow	Dryland Pasture	Other Agric.	Avg. for all Categories
1-Late summer	7.3	8.0	5.8	7.8	8.9	7.2	7.5
2-Late spring	10.0	8.1	3.8	7.3	6.1	6.7	7.0

Overall results for the two seasonal states are comparable (75% for Test 1, 70% for Test 2). EREP S-190A Color IR images acquired in late summer are better for identifying alfalfa and dryland pasture, while rice can be identified with 100% accuracy on late spring images, a marked improvement over the late summer date. These results indicate that (a) neither date would be preferred for overall identification accuracy, and (b) for identification of certain categories, such as rice, alfalfa and dryland pasture, the choice of image type should be specified.

The overall results obtained for all image types at each of the two dates are as follows (from Tables 30 and 32):

Image Type	Overall Results Correct Responses (all crop categories) 1/	
	Late Summer	Late Spring
EREP S-190A Color IR	7.5	7.0
ERTS Color Composite	7.4	6.1
EREP S-190B Color	6.8	-
EREP S-190A Color	6.7	7.1
EREP S-190A B/W-IR	6.6	5.4
ERTS Band 7	6.4	5.6
EREP S-190A B/W Red	6.0	5.8
ERTS Band 5	5.5	5.9

1/ Maximum possible = 10

In all but two cases (EREP S-190A Color and ERTS Band 5), the late summer date is slightly better than the late spring date. However, the magnitude of the differences is not great enough to suggest a strong preference for either date.

2.7.1.3 TEST 3 - STRATIFICATION OF RICE-GROWING REGIONS

The utility of one ERTS and one EREP image for stratification of a portion of the rice-growing region in the Northern Great Valley Test Region

was determined. A 17 square mile area was interpreted by each of 10 interpreters. At an early season date (see Figure 22), most rice fields have been flooded and seeded and their identification is facilitated. Each interpreted overlay was compared to a ground data map. Dot grids were used to determine the area mapped correctly, as well as the non-rice areas incorrectly mapped as rice (commission error). The results of this interpretation are summarized in Table 33. All results are expressed as area in square miles and percentage of the actual rice area (6.75 square miles). Results for both image types are very good, with slightly better results derived from the ERTS color composite than from the EREP S-190A Color IR. These results are reasonable in light of the conclusions of Test 1, i.e., that these two image types are not significantly different for crop identification purposes under the conditions of the study.

2.7.2 NORTHERN GREAT VALLEY AND LOUISIANA COASTAL PLAIN TEST REGION TOGETHER

2.7.2.1 ANALYSIS OF PHOTO INTERPRETATION TEST RESULTS OF SKYLAB DATA

Three different image types taken from Skylab were tested in a separate series of formal photo interpretation tests to determine the usefulness of each for identifying rice and associated crops in both California and Louisiana. Analyzing by Tukey's method of comparing means ("t" test) revealed that S-192 (multispectral scanner) color combined data taken August 4, 1973 in Louisiana was significantly better than S-190B color film of Louisiana and S-192 color-combined data taken of California rice fields on September 12, 1973. That same S-192 data was only marginally better than S-190A color film taken of the Louisiana rice fields.

Table 33. Interpretation Results From Test 3
Delineation of Rice-Growing Areas
(Late Spring Seasonal State)

Item	ERTS Color Composite		EREP S-190A Color IR	
	Area (Sq. Miles)1/	Percent	Area (Sq. Miles)1/	Percent
Actual Rice Area (from ground data)	6.75	100.0	6.75	100.0
Correct Identification	6.12	90.7	5.54	82.1
Commission Error	0.20	3.0	0.52	7.7

1/ Mean values for ten interpreters

It was apparent to project staff that the September 12, 1973 Skylab coverage of the California sites did not provide a realistic test of the usefulness of the data for crop identification under optimum conditions because of the highly variable crop appearance on the photo date as the rice matured. At that date some early rice had been harvested, some was mature, displaying a typical greenish-yellow color and some was green and still growing. Other crops were in a similarly variable condition at that time, hence causing difficulty in identifying crops by their image color.

While we received only one date of S-192 data in Louisiana (taken as the rice crop was maturing) the color differences provided separation of rice from its associated crops for fields that were above the minimum resolution size (15-20 acres) with relative ease. However, analysis of aerial photography taken for the project at an earlier growth stage (when the two primary crops in our test region, rice and soybeans, were not colored by maturing foliage) indicated that color differences would provide a more certain identification of crops at the earlier growth stage.

The Louisiana S-190A photo was significantly better than the S-190B color photo at the .95 probability level which indicates for these examples that higher resolution alone does not assure more useful results.. (See Tables 34, 35, and 36) and Commission/Omission Tables in Appendix E.)

2.8 SUBJECTIVE TEST PROCEDURES

2.8.1 NORTHERN GREAT VALLEY TEST REGION

2.8.1.1 MINIMUM FIELD SIZE AND GENERAL LAND USE

Time available for formal interpretation testing was limited and certain questions did not lend themselves well to the formal testing procedure.

Table 34. Percent Error in Interpretation by Ten Interpreters for Four Image Types in Two Agricultural Regions

Group	Interpreters	Image Types and Areas			
		Color S-190B La*	Color S-190A La*	Color S-192 La*	Color S-192 Sutter‡ S-192 Marysville‡
1	Ve	18	14	18	42
	S	18	11	14	33
	M	25	21	11	43
	Ha	21	18	11	27
	O	21	18	21	35
	$\overline{X}$	20.6	16.4	15.0	36.0
	$SE_{\overline{X}}$	1.29	1.75	1.97	2.97
2	P	25	21	25	42
	L	21	21	4	25
	Vo	25	18	21	47
	Ho	18	21	14	33
	C	21	18	14	42
	$\overline{X}$	22	19.8	15.6	37.8
	$SE_{\overline{X}}$	1.34	.73	3.59	3.92
	Grand $\overline{\overline{X}}$	21.3	18.1	15.3	36.9
	Grand $SE_{\overline{\overline{X}}}$	.91	1.06	1.93	2.34

*La = Louisiana

‡Percentage figures for Sutter and Marysville areas in California have been combined.

Table 35. Significance of Difference Matrix Comparing Image Types by Test Interpreters in California and Louisiana Rice Fields

Image Type	190B Color La 21.3	190A Color La 18.1	192 La 15.3	192 Ca 36.9
190B Color-La 21.3	X			
190A Color-La 18.1	3.2 *	X		
192-La 15.3	6.0 *	2.8	X	
192-Ca 36.9	-15.6 ***	-18.8 ***	-21.6 ***	X

Ca=California La=Louisiana

t Tests

190A Color-La/190B Color-La	t = -2.29 df18	*
192-LA/190B Color-La	t = -2.81	<u>*</u>
192-LA/190A Color-La	t = -1.27	
192-Ca/190B Color-La	t = 6.23	***
192-Ca/190A Color-La	t = 7.33	***
192-Ca/192-LA	t = 7.13	***

$t_{(.90)} = 1.734$, + Significant at P = 0.90

$t_{(.95)} = 2.101$, * Significant at P = 0.95

$t_{(.98)} = 2.552$, <u>*</u> Significant at P = 0.98

$t_{(.99)} = 2.878$, ** Significant at P = 0.99

$t_{(.999)} = 3.922$, *** Significant at P = 0.999

Table 36. Mean Number of Correct Responses per Interpreter
Louisiana Summer Season (7 is maximum correct)

Image Type	Crop Category				
	Rice	Soybeans	Pasture	Fallow	All (average)
EREP S-190B Color	6.8	4.3	3.9	7.0	5.5
EREP S-190A Color	6.7	4.1	5.1	7.0	5.7
EREP S-192 Color	6.1	4.9	5.7	7.0	5.8

A subjective analysis of eight different image types was performed by experienced members of the project staff who judged the minimum field size consistently detected and the certainty with which land use categories could be identified on the test images. The subjective analysis was documented by preparing tables listing each of the various film/filter/system combinations and placing interpretation results in the appropriate columns.

Agricultural fields of known sizes were studied on each image type and the minimum field size consistently identifiable was recorded as a range of values for both high and low contrast targets. In a separate analysis, tables were prepared listing various land use categories and the degree of certainty of detecting and identifying the various land use classes. One tabular display shows the certainty of identification for interpretation of single images. Another was prepared for results from viewing two images at a time, side-by-side, by visual comparison of each feature of interest.

2.8.1.2 SEASONAL ASPECTS AND FREQUENCY OF COVERAGE

The seasonal aspects of agricultural interpretation were also considered, as well as the frequency of image coverage available.

For the Northern Great Valley of California, sequential ERTS-1 coverage was available for the periods from mid-April through September. Using these images taken at 18-day intervals, certain judgments were made regarding the frequency of coverage desired from an observation satellite. A discussion of these finds is contained in Section 3.9.1.

2.8.1.3 CROP VIGOR EVALUATION AND PLANT STRESS DETECTION

Also included as a phase of qualitative testing was the assessments of the role of ERTS and EREP imagery for evaluating crop vigor and detecting

plant stress. The investigators relied heavily upon the experience they have gained from on-going ERTS and SKYLAB experiments to draw conclusions regarding the utility of data from both satellite systems for vigor and stress assessment (Section 2.9.1.3).

2.8.1.4 MULTIDATE IMAGE ENHANCEMENT

Interpreting multidate and multiband images is often a difficult process when done by purely manual means--that is, by visually viewing one image at a time and comparing its information content with that of another image. Several methods of combining multiple images are in use that greatly simplify the display of these images. With these methods, certain unique colors or tonal values are assigned to particular features of interest.

A limited number of image enhancements have been prepared for this study which take advantage of the unique color associated with a particular vegetation type when images of the same area from two dates have been combined by additive color projection.

A variety of image combinations can be made, such as using various bands on various dates and even using both positive and negative images in producing additive color photos. Obviously, much unproductive effort can be applied to making various additive color images unless careful thought is given to the component photos used before starting.

2.9 SUBJECTIVE TEST RESULTS AND ANALYSIS

2.9.1 NORTHERN GREAT VALLEY TEST REGION

2.9.1.1 MINIMUM FIELD SIZE AND GENERAL LAND USE

The relative merits of each image type for detecting and delineating individual agricultural fields was assessed. It was recognized that the ease

with which individual fields can be detected is a function of both the spatial and spectral resolution characteristics of the images. Fields of low or high tone or color contrast can be discriminated if the image has sufficiently high resolution. As resolution becomes poorer, fields which contrast sharply with their surroundings are still discernible. However, fields having low tone or color contrast in comparison to their surroundings are not easily detectable.

These statements are substantiated by the subjective estimates of minimum detectable field size (Table 37). The order of these estimates also correlates well with the ranking of expected resolution (NASA estimates) for each image type (listed from poor to good):

Image Type	NASA Estimate of Expected Resolution (Ft.)	Minimum Field Size (Acres) Extracted from Table 10	
		High Contrast	Low Contrast
S-190A B/W IR	223	8-12	30-40
S-190A Color IR	187	8-12	12-17
S-190A B/W Red	91	3-5	5-10
S-190A Color	78	3-5	5-8
S-190B Color (high res.)	50	3-5	5-8

In all cases, fields of high tone or color contrast can be discerned at smaller size limits than fields of low contrast. The nominal resolution of the last three images listed above permits substantially smaller fields to be discerned than does the resolution of the first two images.

A similar case can be made for ERTS imagery. In this case, the spatial resolution of the three ERTS images used is theoretically fixed by the inherent pixel size. The process of generating the color composite image from three separate MSS bands might logically be thought to result in an image of even lower resolution than the black-and-white bands, five and seven.

Table 37. Minimum Agricultural Field Size (Acres) Consistently Detected on EREP and ERTS Images

Contrast	EREP - September 12, 1973					ERTS MSS - September 13, 1973		
	S-190A				S-190B			
	B/W Red	B/W IR Band	Color	Color IR	Color	Band 5	Band 7	Color Composite 4, 5 & 7
High	3-5	8-12	3-5	8-12	3-5	10-20	10-20	10-15
Low	5-10	30-40	5-8	12-17	5-8	30-40	30-40	20-30

However, the improvement in color contrast afforded by a color image permits the detection of smaller (not larger) fields than is possible on the black-and-white images:

ERTS Image Type	Minimum Field Size (Acres) (Extracted from Table 37) High Contrast	Low Contrast
Band 5	10-20	30-40
Band 7	10-20	30-40
Color Composite (Bands 4, 5, 7)	10-15	20-30

Especially for low contrast targets, this added spectral discrimination (resolution) of the color composite is valuable for detecting smaller fields.

In comparing EREP and ERTS data, one can draw comparable conclusions regarding minimum field size for the ERTS images as a group compared to the EREP S-190A B/W IR image. Only this EREP image type was similar to the ERTS images, however. With all other EREP images, smaller fields could be detected as image resolution increased. Subtle improvements were observed between the S-190A B/W red image and the S-190A and S-190B color images. The increased spectral discrimination of individual fields using a color image in comparison to a black-and-white image is suggested as the most significant reason, even though slight spatial resolution differences also exist for these image types.

Another question of interest in these subjective studies dealt with identifying and delineating land use in the Northern Great Valley Test Region. Using the same images as presented to the test subjects in this study, a series of land use categories was listed and the certainty with which positive identification and boundary delineations could be made by interpreting one image at a time was estimated by non-testing (subjective) analysis. The results of that

effort appear in Table 38. The same type of analysis was made while comparing various combinations of EREP and ERTS images. The results of that effort are listed in Table 39. In each of these tables, subjective interpretation certainty is given by the following rating scale:

1 = certain
2 = probable
3 = possible
4 = uncertain

The relative ranking of the 8 image types for single interpretation was determined by summing the interpretation certainty for the various land use categories:

Image Type	Total Certainty Ranking[1/]
EREP S-190B Color	8
EREP S-190A Color	11
EREP S-190A Color IR	14
ERTS Color Composite	15
EREP S-190A B/W Red	16
EREP S-190A B/W IR	19
ERTS Band 7	20
ERTS Band 5	22

Although significant differences cannot be derived from this array, it does represent the concensus of the investigators regarding the interpretation of general land use categories, and suggests the magnitude of relative accuracy ratings.

In general, interpretation of two images in concert results in slightly improved interpretation accuracy for some image pairs, and no improvement for others. Ratings of the pairs of black-and-white images improve when

[1/] 6 = certain ranking for all categories.

Table 38. Interpretation Certainty for Land Use Identification and Delineation (Late Summer Seasonal State - Single Image)

	EREP - September 12, 1973					ERTS - September 13, 1973		
	S-190A				S-190B			
Land Use Category	B/W Red	B/W IR	Color	Color IR	Color	Band 5	Band 7	Color Composite
Agriculture	2	2	1	2	1	3	3	2
Dryland Pasture	2	3	2	3	1	3	3	2
Woodlot	4	4	3	2	2	4	4	3
Urban	2	4	1	3	1	4	4	4
Unused Land	3	4	2	2	1	4	4	3
Water Bodies & Drainage	3	2	2	2	2	4	2	1
Total	16	19	11	14	8	22	20	15

Key to Interpretation Certainty:

1 = Certain
2 = Probable
3 = Possible
4 = Uncertain

Land Use Category Legend:

Agriculture - cultivated land
Pasture - natural grassland used for livestock grazing or watershed
Urban - residential, commercial, industrial; small and large cities
Unused Land - dumps, floodplains, wasteland
Woodlot - farm tree lots, 20 acres or larger in size
Water Bodies and Drainage - lakes, reservoirs, ponds, rivers, streams

Table 39. Interpretation Certainty for Land Use Identification and Delineation (Late Summer Seasonal State - Multiple Images)

	EREP S-190A - September 12, 1973						ERTS - September 13, 1973		
Land Use Category	B/W Red & B/W IR	B/W Red & Color	B/W Red & Color IR	B/W IR & Color	B/W IR & Color IR	Color & Color IR	Bands 5 & 7	5 & Color Composite	7 & Color Composite
Agriculture	2	1	1	1	2	1	3	2	2
Dryland Pasture	2	2	2	2	3	2	3	2	2
Woodlot	4	3	2	3	2	2	4	3	3
Urban	2	1	2	1	3	1	4	4	4
Unused Land	3	2	2	2	2	2	3	3	3
Water Bodies & Drainage	2	2	2	2	2	2	2	1	1
Total	15	11	11	11	14	10	19	15	15.

Key to Interpretation Certainty:

1 = Certain
2 = Probable
3 = Possible
4 = Uncertain

they are interpreted together. However, interpretation of a color or color IR image is not improved by the addition of information from a black-and-white image.

2.9.1.2 SEASONAL ASPECTS AND FREQUENCY OF COVERAGE

Parallel studies have been conducted for the rice crops on the Coastal Plain of Louisiana and the Northern Great Valley of California using EREP and ERTS data. For California, weather conditions during the 1973 rice growing season were favorable for satellite image coverage and an excellent series of ERTS coverages was acquired on the 18-day cycle.

In Louisiana, on the other hand, weather conditions during 1973 were unfavorable and a complete series of images was not acquired during the growing season from either ERTS or the Skylab satellite. One usable ERTS image was acquired at the beginning of the season during planting of the rice crop and one was acquired at the end, after harvest. Only one late season (August 4) coverage was obtained of the Louisiana test region during the 1973 rice growing season from Skylab. Such problems can be anticipated in those agricultural areas characterized by high atmospheric humidity and persistent daytime cloudiness.

Because of certain critical rice crop events (planting, emergence, heading and harvest) the 18-day period for repeat cloud-free ERTS coverage is acceptable. However, if one or more of those sequential overflights is lost due to cloud cover, the time span between image dates during critical crop events becomes unacceptable, as it was in Louisiana during 1973. Weather records of the Louisiana test region have not been analyzed to

determine what frequency of overflights would have provided adequate coverage during the growing season. Obviously, the 18-day cycle was not satisfactory.

Photographic image quality is an important factor which greatly impacted interpretability of land use categories on sequential ERTS imagery. The certainty with which each of several land use categories can be identified was determined for various ERTS and EREP images acquired throughout the 1973 growing season (Table 40). Band registration, color fidelity and print density are the three aspects that varied from one date to the next in this series of images. In addition, atmospheric effects such as haze and cloud cover influenced the interpretability of some of these images.

It should be noted that the ERTS image of the highest quality in all factors - atmospheric clarity, color fidelity, band registration and print density - was the September 13, 1973 color composite supplied to the investigators. This factor is reflected in Table 40 where it was possible to identify with certainty all land use classes except woodlots on that frame. Some other ERTS prints provided were of relatively poor quality, such as the July 21, 1973 ERTS color composite. Skylab reproductions were fully satisfactory for evaluation purposes. It is not possible to make meaningful judgments regarding image interpretability for some features when print quality is variable.

2.9.1.3 CROP VIGOR EVALUATION AND PLANT STRESS DETECTION

Of all images tested in this study, color infrared images provided the best means to detect differences in crop vigor and for detecting plant stress caused by drought, soil deficiencies, disease, etc. Color infrared images record the spectral energy reflectance differences that occur between vigorously growing plants and stressed or damaged plants. In the near

Table 40. Multidate Interpretation of Land Use Identification and Delineation

	Image Type and Date (1973)									
Interpretation Certainty	ERTS CC 4/22	ERTS CC 5/10	ERTS CC 5/28	ERTS CC 6/15	ERTS CC 7/3	ERTS CC 7/21	ERTS CC 9/13	EREP S-190A Color 6/3	EREP S-190A Color 6/12	EREP S-190B Color 6/12
1	APW	APW	APW	APW	APW	APW	APW BU	AP	AB	AP UB
2	U	UB	U	UB	UB	UB		UW	PUW	WT
3	B		B					BT	T	
4	T	T	T	T	T	T	T			

Land Use Legend:

A = Agriculture
P = Pasture
T = Woodlot
U = Unused Land
B = Urban
W = Water Bodies

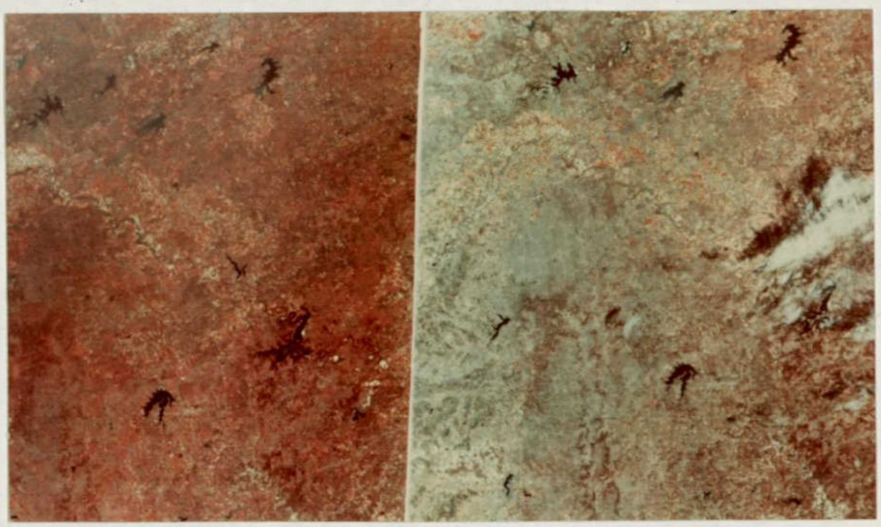
Key to Interpretation Certainty:

1 = Certain
2 = Probable
3 = Possible
4 = Uncertain

infrared spectral region, healthy plants reflect relatively high amounts of energy while stressed (unhealthy, wilted) plants reflect relatively low amounts of energy. This factor, coupled with the fact that the near infrared region is not as seriously affected by atmospheric haze as the visible spectrum, makes color infrared sensing an ideal method for recording information on plant vigor and stress when used from space and high flying aircraft.

A study of numerous ERTS color composite images (color IR simulations using bands 4, 5, and 7) acquired over a variety of vegetation scenes and several dates confirm that spectral reflectance differences in plant vigor and plants under stress from soil nutrient or moisture deficiencies can be distinguished visually from those plants that are healthy. An excellent example of this situation was observed by comparing an ERTS color composite image (1256-16421) of Northern Texas taken on April 5, 1973 with a color composite image (1616-16362) taken at about the same time (March 31) in 1974, when severe drought conditions were experienced. As seen in Figure 32 these two color prints display a significant difference in overall red coloration because of the influence of drought in the 1974 period.

It is interesting to note that, in the Northern Texas drought region (Young County) where these photos were taken, the predicted 1974 winter wheat crop yield was about half as great as the actual 1973 winter wheat crop yield, in spite of an estimated 22% increase in wheat acreage planted for 1974 crops. In this case, the image differences correspond to significant differences in yield. Similar differences in plant vigor were visible on other ERTS color composites in the Northern Great Valley of California where stressed fields were observed as a result of soil nutrient and mositure deficiencies.



April 5, 1973 March 31, 1974

Figure 32. ERTS prints of North Texas (Young County) wheat growing area affected by extended drought in 1974. Print on left was taken April 5, 1973. Note overall reddish color indicating presence of growing plants. Print on right was taken March 31, 1974. Note absence of reddish color due to drought except in isolated agricultural areas where some irrigation has taken place. On the transparencies from which these prints were made, it was possible to detect significantly lower levels of water in lakes and reservoirs on right-hand print taken during the drought period than on the left-hand print. The presence of the reddish color on the left print is even more apparent on the original transparencies than on these copy prints.

The minimum field size in which plant vigor problems can be detected is determined by several factors, including surface area affected, severity of the problem and characteristics of surrounding plants and soils. Perhaps the most useful analysis that can be made at the ERTS resolution level involves comparing images of a scene taken over a period of time whereby changes in red coloration of selected regions are observed and correlated with known ground conditions (drought, disease, etc.).

As noted earlier in this report (Table 37) even for high contrast ground features the smallest field that can be detected on ERTS images is 10-15 acres. Most plant stress situations have low contrast image signature. This requires that such anomalies have an areal extent of at least 20-30 acres for consistent detectability.

For EREP S-190A color IR images, the minimum detectable field size is 12-17 acres for low contrast targets, and for EREP S-190B high resolution color images, the size drops farther to the 5-8 acre range for features of low contrast.

It is recalled that for regional crop surveys a range of minimum field sizes detectable at the level of 20-30 acres seems reasonable, but for the data to be useful to the farm manager (who can take corrective action if notified of a condition in time) a minimum detectable stressed area size of 5-10 acres is much more desirable. The question of minimum field size depends largely, however, on the size of farms being managed as a unit, cost of various corrective measures versus associated benefits, and farm practices common to the region concerned. It has been noted from past experience with high resolution aerial photos that, even when detailed information on crop problems is available to the farmer from aerial photo interpretation, corrective actions

are often reluctantly taken because of the high costs involved. Only in some of the more progressive farm regions have the use of aerial photographs been exploited to any degree for operational crop management.

For an ERTS-type system to provide a low contrast minimum field size detectable at the 5 acre level, a minimum size of perhaps 1 or 2 acres for high contrast fields should be set as a detectability range. From Table 37 it is apparent that such a change would require a spatial resolution improvement of 1/5 to 1/10 or more over present levels. Whether such a change can be justified at present levels of costs, technology and data benefits is very questionable since many farms are presently not in a position to utilize such data even if it were available on a timely basis. The data dissemination problem (making current information available to farmers on a weekly if not semi-weekly basis) is extremely complex and therefore the question of improving resolution for farm use may not be the controlling factor.

A limited assessment of the recognition of lodging on rice fields was undertaken. Portions of rice fields which are lodged (plants have been blown over by winds or other disturbance) are more difficult to harvest, and reduced yields of varying magnitudes result. For purposes of crop forecasting, lodging estimates are important inputs to the prediction of yield reduction at the appropriate stages of crop development.

A number of low altitude aerial oblique photographs were taken prior to (August 28, 1973) and coincident with (September 13, 1973) the ERTS and EREP overpasses of the Sutter and Marysville Test Sites. The proportion of individual fields containing lodging and the location of lodged areas within each field are easily seen on these photographs (Figures 33 and 34). The corresponding areas covered by these photographs were studied on each of

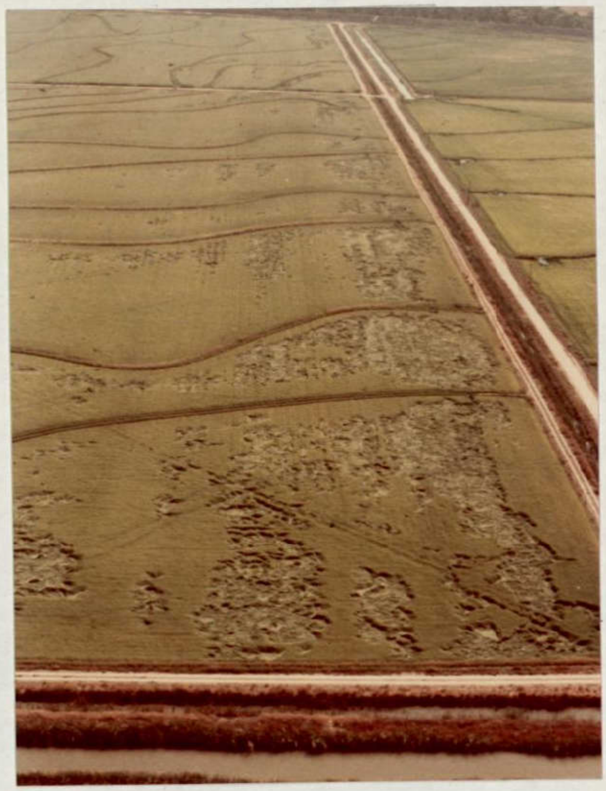


Figure 33. Example of lodged rice in the Sutter Test Area (August 28, 1973).

Figure 34. Example of lodged rice in the Marysville Test Area (September 13, 1973). The light color of lodged rice contrasts more sharply with standing rice in the dark fields on the right which have not begun to dry and mature than with the standing rice in the light fields on the left which are already maturing.

the EREP and ERTS positive transparency images as well as on color and color IR high altitude aircraft photographs (scale 1:120,000) acquired coincident with the ERTS and EREP overpasses.

The detection of lodged rice areas is more dependent upon spatial than spectral resolution. Lodged areas were easily recognized on the high altitude aircraft color and color IR photographs. The light color of lodged areas contrasts well with the darker color of standing grain (see also Figure 34). The difference is as apparent with either film type.

Many areas of lodging were clearly evident on the EREP S-190B color image. The resolution of this system (NASA estimate = 50 feet) was sufficient to recognize the lodging pattern evident in the area of Figure 33, while the lodging in Figure 34 appeared only as a subtle color difference. Only large, sharply defined areas of lodging were discernible on the EREP S-190A color image. Its resolution (NASA estimate = 78 feet) was judged to be markedly poorer than the EREP S-190B color for lodging detection. It should be noted that an occasional large lodged area could be picked out on the ERTS color composite, but only with prior knowledge as to its location.

The only possible feature that might be confused with lodging at this date is the pattern of early maturing rice. Patches of a field which ripen prematurely (due to early drying of parts of fields) resemble lodging in that they are also light in color. The overall incidence of early maturity of parts of fields is much less common than lodging of an entire field. Hence, this confounding factor is not judged to affect significantly the conclusions reached above.

2.9.1.4 MULTIDATE IMAGE ENHANCEMENT

A limited number of multidate additive enhancements were prepared as part of the subjective analysis for crop identification to enhance the pattern of rice culture during 1972 and 1973. In particular, three categories of rice culture were distinguished:

a) fields containing rice during both 1972 and 1973

b) fields containing rice in 1972 and another crop in 1973

c) fields containing another crop in 1972 and rice in 1973.

Information of this type has a variety of uses, including a) the study of crop rotation and fallowing practices (for individual fields and on a regional basis), and b) the assessment, on a regional basis, of the year-to-year variation in total acreage devoted to rice culture.

Only ERTS imagery was used for enhancement of year-to-year changes because the Skylab imagery acquired fell entirely within the 1973 growing season. Nevertheless, enhanced images generated from ERTS data are suggestive of the type of product that can be created from any type of multiband satellite image. The I^2S Addcol (additive color viewer) was used to produce the examples described below.

The enhancement procedure used is summarized as follows:

Image Type/Date	Filter	Image Color Derived on Each Date: Rice	Image Color Derived on Each Date: Other Agricultural Crops
ERTS Band 5/July 26, 1972	Red	Dark	Red
ERTS Band 5 /August 8, 1973	Blue	Dark	Blue

An example of the enhancements produced by this setup appear in Figure 35 (Marysville Test Site). Within the rice-growing areas

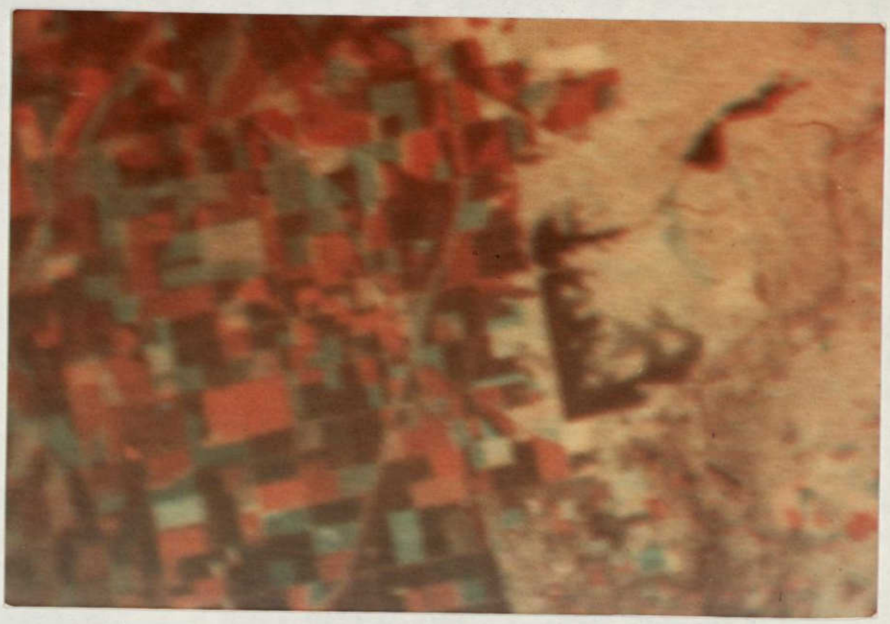


Figure 35. Multidate additive color enhancement of the Marysville Test Area. Within the rice growing areas characterized by large fields of rectangular shape, the color codes have the following significance: dark: rice in 1972 and 1973; blue: rice in 1972, other agricultural crop in 1973; red: other agricultural crop in 1972, rice in 1973.

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(characterized by large fields of rectangular shape) the color sequence on the enhanced images is as follows:

1972 Crop	1973 Crop	Color on Enhanced Images
Rice	Rice	Dark
Rice	Other agricultural crop	Blue
Other agricultural crop	Rice	Red

Comparison of the enhanced images with maps of ground data document the above sequence.

It must be stressed that the multidate or multiband enhancement process is successful only if the input images contain inherent spectral or temporal differences. The enhancement procedure can facilitate or enhance the interpretation of multiband or multidate images that meet this criterion. In addition, the enhancement procedure must be implemented by persons knowledgeable in the objectives of each enhancement as well as the signatures of each category on the input image. In this way the effectiveness of the enhancement procedure can be maximized.

2.10 AREA ESTIMATION FOR AGRICULTURAL FIELDS

An investigation of the usefulness of various camera systems for estimating area of rice fields, using a visual dot counting method and a planimeter, was performed. It was found in this study that for regional determinations of groups of fields comprising over 3,000 acres the total area of rice could be estimated with no more than 7% error using any of the systems tested. Table 41 summarizes the results of the investigation of two methods for area estimation from photo interpretation--visual dot counting and planimeter measurement. In each case the number of dots on a transparent overlay or graduations on the planimeter dial correspond to ground area

Table 41. Error Associated with Area Determination in Rice Fields by Dot Count and Planimeter

System	Total Area Measured (Ground truth)	Estimated Area			
		Dot Count (64 dots/sq. in.)		Planimeter (100 units/sq. in.)	
		Area	Error	Area	Error
S-190A color	3485	3584	+.028	3588	+.030
S-190A CIR	4594	4456	-.030	4276	-.069
S-190B color	4594	4623	+.006	4502	-.020
skylab support aircraft	9188	9039	-.016	9216	+.003

in acres when converted by a formula that relates photo scale and number of dots or graduations to ground acreage.

3.0 SUMMARY

Satellite photos of the quality provided by the Skylab EREP system were shown to be useful for agricultural crop monitoring for identifying rice and associated crops including alfalfa, pasture, soybeans, orchards, vineyards, and fallow ground. In order for this condition to be met, photos should be taken at several critical crop stages (soil preparation, flooding, and full cover by rice foliage) and in multiple spectral bands that are used in color infrared film (green, red, and near infrared). These bands should be displayed as a color composite image when an MSS is used, and color infrared film should be used in camera systems for this application. For crops to be identifiable and their field boundaries visible (minimum 5 acre field size), it was necessary to have spatial discrimination (resolution) of the level available in the S-190B system.

By a combination of both spectral discrimination that separated the crops of interest and spatial discrimination that allowed fields (boundaries) to be resolved down to the minimum required size, it is possible to identify and map fields of interest using space photos taken at specified times during the growing season. The errors decreased when photos taken during two or more seasonal states were included in the interpretation. If crop identification was performed on photos taken at harvest time alone, errors increased significantly because of the non-uniform appearance of fields supporting the same crop.

For stress and vigor determinations leading to yield estimates and for use in making crop management decisions regarding needed cultural manipulation (irrigation, weed control, harvest, etc.), the Skylab photos provided were not satisfactory because of limited spatial

discrimination characteristics. While stress and vigor factors are quite variable in physical appearance and occur at different times, it was demonstrated that color infrared photos taken from aircraft at scales of 1:30,000 and larger provided the interpreter with very useful information regarding crop growth problems.

Each crop has a unique crop calendar, i.e., characteristic growth appearance and schedule, thus making it possible in any given agricultural region to identify a crop from its nearby associated crops by observing ground scenes at those times when the desired discriminations can be made. For example, rice as it is cultivated in many parts of the world is typically grown in standing water 4" to 8" (10 to 20 cm.) deep for nearly all of the crop season. It therefore has a unique appearance from the time the field is first flooded until the foliage completely obscures the water from the aerial view. This characteristic alone permits rice fields to be identified with very high accuracy even on space photos when taken in the near infrared spectral band where standing water appears dark and surrounding fields and vegetation appear light in tone. Later in the growing season other crops, that are grown in association with rice and appear similar from the small scale aerial view, cannot be readily separated from rice because both cover the ground in a uniform continuous mat (i.e., their crop calendars from the standpoint of spectral reflectance tend to coincide at that particular time). In that situation where spectral discrimination is not possible using the aforementioned near infrared part of the spectrum, one must increase the spatial discrimination characteristics of the imagery through larger scale to permit the interpreter to see clearly ground detail that indicates the crop identity. In the case of rice, the characteristic contoured water control levees from "rice checks" or

strings of rice planting within which water depth is controlled at the desired depth and differs slightly from adjacent check (usually by at least 12 centimeters) in ground elevation. These features are not visible consistently on Skylab space photos but can be discerned on larger scale aerial photos (1:30,000 or greater).

Thus, it can be said that there is a seasonal trade-off between spectral and spatial discrimination requirements for rice identification, i.e., at certain times in the crop growing season spectral discrimination provides identification while at other times spatial discrimination is required.

The analysis of photo interpretation testing for crop identification and stress detection indicated that the S-192 color composite (channels 1, 7, and 9--blue, far red, and near infrared) provided excellent spectral discrimination of crops but with limited spatial discrimination for field smaller than 20 acres in size. The S-190A and S-190B color images, on the other hand, provided higher spatial discrimination values but did not provide adequate spectral discrimination. The S-190A color infrared photography was significantly better than all other systems tested and rated equally as useful as the ERTS-1 color composite tested for crop identification. The use of color infrared images consistently has been shown to be superior to conventional color images for crop identification and monitoring of crop stress, vigor, and progression relative to a crop calendar. The higher spatial discrimination provided by the S-190B and supporting aircraft photography is needed for monitoring of crop stress and vigor given an acceptable level of spectral discrimination.

3.1 CONCLUSIONS

3.2 SYSTEM REQUIREMENTS

Several of the factors that tend to reduce the yield of agricultural crops can be assessed on aerial photography. These factors include the presence of various insects, diseases, weeds, mineral deficiencies, and mineral toxicities as well as drought, flooding, sun scald, frostbite, and wind throw (e.g., lodged grain).

In order to assess accurately on aerial photos the degree to which each of these factors affects crop yield, it is imperative to take the photography to appropriate specifications which will permit detecting the extent and severity of each factor. For rice crops the bands exploited in color infrared photography provide tonal values suitable for the making of these determinations.

Furthermore, the photographic scale must be large enough to make the necessary determinations, yet small enough to permit use of the method at flight altitudes which the user will consider operationally feasible. Also, it is essential to photograph the crop areas during times when each of the yield-reducing factors can be accurately assessed. A limited amount of field checking is required to provide a basis for determining the accuracy with which the extent and severity of each factor can be determined by aerial photo interpretation. This field checking also permits yield reduction factors to be determined for the various photo identifications made.

In most cases yield estimates on a field-by-field basis cannot be made using EREP or ERTS images alone because of the limited resolution characteristics of EREP and ERTS data. Many of the yield-limiting factors

occur in small areas and are scattered so that they are not detectable on EREP images (note following tabulation):

ADVANTAGES AND LIMITATIONS OF ERTS, EREP AND SUPPORTING AIRCRAFT PHOTOGRAPHY

IMAGE TYPE	ADVANTAGES	LIMITATIONS
ERTS MSS	Broad area coverage on a repeatable basis. Excellent spectral capabilities. Data are computer compatible.	Resolution limited to regional interpretations to a ten acre minimum size. Imagery not useful for day-to-day crop management decisions on a farm basis. Time constrained.
High-flight Photography	Medium area coverage on a scheduled day-to-day basis. Cameras and spectral bands readily changeable. Spatial resolution permits semi-detailed interpretation for crop analysis and management decisions on a two-to-three acre basis and larger.	Requires careful flight planning and execution to insure correct coverage. Cannot cover as large an area as with spacecraft.
Low-flight Aircraft	Small area coverage on a scheduled day-to-day basis. Cameras and spectral bands readily changeable. Spatial resolution permits detailed interpretation for crop analysis, evaluating plant stress and vigor and making management decisions on a less than acre basis.	All factors listed for high-flight aircraft apply here. Areas covered are even less. Repeatability of ground track becomes a problem.

IMAGE TYPE	ADVANTAGES	LIMITATIONS
Skylab EREP S-190A	Broad area coverage on a repeatable basis. Multiple film-filter combinations can be used. Spatial resolution permits semi-detailed interpretation for regional crop management decisions on a five-to ten-acre basis and larger.	Requires handling of camera film and recovery of exposed film. Resolution limited. Time constrained.
S-190B	Medium area coverage on a repeatable basis. Single high-resolution camera film system for semi-detailed interpretation for local and regional crop management decisions on a three-to-five acre basis.	Same as S-190A.
S-192	Broad area coverage on a repeatable basis. Multi-spectral capabilities. Data are computer compatible.	Resolution limited to regional interpretations to a five-acre minimum. Time constrained. Requires complex processing equipment.

In a comparative study of Skylab and ERTS imagery[1] it was found that the minimum agricultural field sizes consistently detectable on EREP imagery were in the three-to-five acre range depending upon contrast with surrounding features. Thus, problem areas occurring in small patches are not detectable on EREP images. In those cases higher resolution images such as those provided by aircraft camera systems are needed to reveal the presence of crop limiting agents.

3.3 PARAMETERS DETERMINING YIELD

The three primary factors affecting yield determinations as made, field-by-field, on photography are field area, plant density, and plant vigor.

3.3.1 FIELD AREA

Field area can be measured directly on aerial photos by various means. On EREP photos area measurements may be made on groups of fields where field sizes are too small for individual delineation. In this case a correction factor is frequently applied to compensate for roads, farm buildings, and irrigation and drainage canals that are included. The making of field area measurements is essentially a mechanical process once the crops have been identified and their boundaries delineated. Among the devices most commonly used in measuring field areas on vertical photos of known scale are:

[1]A Comparison of Skylab and ERTS Data for Agricultural and Natural Vegetation Interpretation, Technical Report, July 1, 1974. Earth Satellite Corporation. NASA Contract No. NAS 9-13286.

a. The polar planimeter. An initial reading is made on the planimeter's dial. A pointer attached to one end of the planimeter's arm is then used to trace out the field's photo boundary, thereby changing the reading on the dial. The difference between initial and final readings on the dial provides a measure of the field's area.

b. The dot grid overlay. Each of the uniformly-spaced dots on a transparent plastic overlay represents a known field area, depending on photo scale and dot spacing. The overlay is randomly oriented over a vertical aerial photo on which the field's boundary has been delineated. The total number of dots falling within the field is multiplied by the calculated area represented per dot to estimate the field's area.

c. The line transect overlay. Each unit of length on each of the uniformly-spaced lines of a transparent plastic overlay represents a known field area, depending on photo scale and line spacing. The overlay is randomly oriented over a vertical photo on which the field's boundary has been delineated. The total number of line units falling within the field is multiplied by the calculated area per line unit to estimate the field's area.

d. The laboratory balance. A square which, at the scale of the vertical photo, represents some convenient unit of area (e.g., one square kilometer) is delineated directly on the photo. Usually this is done somewhere in the corner of the photo where no fields that are to be measured appear. Using scissors or a razor blade this square is carefully cut from the photo and weighed on the laboratory balance to establish a weight per unit field area. Each field in turn, for which area is to be

determined, is then cut from the photo and weighed. This weight, divided by the weight per unit area, provides an estimate of the field's area.

e. The density slicer. By electronic image enhancement and determination of percent of area of each density on the film, a relative area of each crop type can be estimated.

f. Digital image readout. In those cases where digital tapes are available, such as for ERTS, EREP or airborne multispectral scanners (MSS), area determination for particular image features having characteristics recognizable by the digital signature can be made by a computer program compatible with a tape reader.

3.3.2 PLANT DENSITY

Plant density for any given field is defined as the percent of the total ground area within the field that is covered by foliage as seen in the vertical view. The state of the development of the crop must be considered in ascribing significance to a plant density figure.

Certain soil characteristics can greatly affect plant density. Principal among these are soil fertility, soil depth, physical structure and moisture content. Soil which has an optimum level of these factors will support a relatively high plant density and can produce a crop of high yield. Increasing the plant density above this level (e.g., by seeding the area too heavily at planting time) will result in a reduction in yield due to the increase in foliage competition for sunlight, and in root competition for nutrients and water. By the same token a decrease in plant density will not fully utilize the carrying capacity of the soil although individual plants will produce well.

Therefore, in agricultural crop management it is important to determine the soil producing capacity for the particular crop to be planted and establish a crop with the desired plant density for the prevailing conditions. Fertilizer, humus, minerals and other materials can be added to the soil to increase crop production up to the maximum level for each factor beyond which a loss in yield will result.

It is difficult to assess on space photography what this optimum plant density level might be due to the complex interrelations that occur. However, it is possible to compare existing plant densities within a field or among several fields appearing on space photographs and to evaluate the relative characteristics, within the various plant density strata, which indicate potential yield such as heading (on cereal crops), foliage color and height. Among the factors which affect plant density are seeding density, seed viability, seed germination, seedling survival and the use or misuse of planting and cultivating equipment. In estimating plant density, the photo interpreter estimates the area of visible foliage structures covering the background soil or water and thus the integrated effect of these factors on crop yield.

3.3.3 PLANT VIGOR

Plant vigor is variously rated in relation to foliage tone or color, plant size and rate of growth. While it is generally true that the more vigorous plants produce a higher yield, other factors are of importance. For example, the faster growing, denser, more vigorous, and more succulent plants may be more susceptible to attack by diseases.

Wind damage is also greater in cereal crops which exhibit these characteristics. Therefore, vigor determinations provide a good basis for yield estimation but only when the other previously listed factors related to vigor are known or are determinable. In attempting to relate apparent plant vigor to crop yield, it is important to know which of the previously listed damaging agents may have contributed to a loss in vigor.

Probably the most important agents responsible for reducing plant vigor and thereby crop yield are those collectively known as "plant pests." It has been determined that in the United States alone about 15 billion dollars annually are lost to the agricultural and forest economy due to the activities of such pests.[1] Each year, about 20% of the food crops of the world are never harvested for the same reason. Only in very severe cases of pest attack would crop damage be detectable on ERTS photos. On aerial photographs, some of these plant pests are readily identifiable and their effects on crop yields determinable, while others are very difficult to identify and assess in relation to yield reductions. Even the agronomist on the ground may have difficulty in detecting these pests and in assessing their severity, extent and effect upon yield of the crops attacked.

3.4 SUPPORTING DATA

Some of the variables encountered in producing agricultural crops can change the potential yield of a field with little change in the visible appearance of a crop. In such instances, historical crop data will prove useful, especially in making regional yield determinations. Other variables

[1] "Report of the Committee on Plant Pests," National Research Council, National Academy of Sciences, 1961.

include information such as crop yield trends for a region over the past ten years, weather data prevailing during crop establishment and at critical periods of crop growth, and indications of increased planting of a crop in areas not normally committed to that crop.

3.5 THE SUBTRACTIVE METHOD OF YIELD ESTIMATION

The photo estimation of yield for a particular crop in a designated region is greatly facilitated if one knows the maximum potential yield which that crop can produce when grown in the region being investigated, i.e., the yield that would be obtained if all potentially limiting factors were absent. Such a condition rarely exists, but information on the potential yield permits a very useful datum to be established. As the various yield-limiting factors are detected on photos at various stages in the development of a crop, appropriate deductions can be made systematically from the potential maximum yield. (See Appendix D.)

In using the technique of reducing yield from a potential maximum, two assumptions are made: (1) given a supply of viable seed typical of the variety grown with success in the study area and a plot of ground properly prepared for growing that crop, the farmer has at the outset the potential of growing a nearly perfect crop with a known maximum yield, and (2) from the day the seed is sown certain yield-limiting factors may become operative.

These factors may be segregated into physical effects and physiological effects. The physical effects pertain to the actual presence or absence of crop producing plants in any part of the field. Obviously, a complete absence of plants will cause a 100% yield reduction for the area involved.

The physiological effects pertain to the presence of pests or other factors which affect the health and vigor and hence the yield of the crop. These factors may affect yield in decidedly different ways depending upon the severity of each factor and the time in the growth cycle of the crop when each took effect. Since the limitations caused by physiological effects cannot be expressed in areas where no plants are present, data reduction processes for each of the types of yield reduction should be considered separately. The loss caused by <u>physical</u> effects can occur at any time during the growth of the crop and can reduce the yield by as much as 100% should physical forces completely eliminate producing plants. On the other hand, yield reductions caused by introduction of <u>physiological</u> effects are greatest at certain periods during the growth of the crop and at other times introducing the same physiological agents will have a relatively small effect upon yield because the crop may have grown past the stage of susceptibility.

The technique described on the following page is based on results actually obtained for rice during tests conducted by the present investigators. It illustrates a typical use of the concepts just described. The realistic assumption was made that, in the vicinity of Sutter, California, the "maximum potential yield" of one variety of rice was 6,000 lbs. per acre. It will be noted that appropriate reductions in yield were made in the various fields, on various dates, as photo interpetation established the presence and severity of various harmful physical and physiological factors.

POTENTIAL YIELD
TECHNIQUE OF DATA REDUCTION
(EXAMPLE)

AREA - Sutter Test Field No. 5
Colusa Variety
220 acres, planted 20 May 1973

PHOTO DATES 5 July 1973, 29 August 1973 — PHOTO SCALE 1/30,000

FILM-FILTER Ekta Infrared — PHOTO QUALITY - Good

POTENTIAL YIELD — 6,000 lbs/Acre

YIELD REDUCTION FACTORS:

A. Physical

Inadequate Seeding	5
Improper Cultivation	0

Total Yield Reduction due to Physical Factors = 5% x 6,000 = 300 lbs.

Maximum Field Potential Remaining = 5,700

B. Physiological

Disease	0
Lodging	0
Weeds	10

Total Yield Reduction due to Physiological Factors = 10% x 5,700 = 570 lbs.

NET YIELD EST BY PI	5,130 lbs/Acre
ACTUAL YIELD FROM GROWER	5,200 lbs/Acre
ERROR IN ESTIMATE	-70 lbs/Acre
ERROR IN ESTIMATE	-1.4%

3.6 DESCRIPTION OF PHOTO DATA REDUCTION TECHNIQUE

The usefulness of aerial and/or space photography for agricultural crop observation has been an established fact for many years. The facts which have not been established pertain to the reliability of estimates of specific crop factors such as: (1) crop vigor and health, (2) type of disease, severity and extent, (3) response of crops to applications of mineral nutrients, herbicides, insecticides, etc., (4) effects on crops of natural influences such as micro-climate, storms, floods, etc., and (5) estimated yield in light of these and other factors.

3.6.1 IMAGE FACTORS

Images of crops can be used for analysis of crop condition if certain facts have been established for the crop in a specific region. These image factors are: (1) relative tone or color of the vegetation, (2) density of the vegetation covering the ground, (3) texture and uniformity of images, and (4) appearance of the crop on sequential photographic coverage.

Although some of the factors which influence the growth of a crop and the ultimate yield attainable in a given area and season can be recorded on space photography taken to proper specifications, it is nearly impossible to separate each of these factors when they occur simultaneously on the same area. Some of these factors affect yield to a high degree while others may have only a very limited effect on yield. The time when each of these factors occurs, and its severity, also influence the effect on yield.

3.6.2 GROUND OBSERVATION VERSUS PHOTO INTERPRETATION

The agricultural expert on the ground, given enough time to observe a crop exhaustively, can estimate the effect of each factor on yield and specify measures for control of some of these factors. In the present rice study aerial photo dates and exposure specifications were determined by reference to past crop studies and by consultation with experts in the areas where these crops were grown. Thus, the frequency of observation and the image records to be obtained were established before each of the critical events took place.

The influence of each of the anticipated events on the crop and its ultimate yield were determined by consultation with these same experts and by reference to pertinent literature. The major limitations to this technique lay in the inability of the photographic image to record every detail of crop condition at the photographic scale ratios desired, and in the inability of the photo interpreter to separate successfully each of these factors from the others.

For example, in the case of wheat stripe rust, the ground observer, using long-established standard procedures, estimates the amount of leaf area affected by the stripe rust pathogen and, depending upon state of development of the crop, subtracts a certain percentage from the final yield. Thus, if the disease attacks just prior to heading, he has learned empirically to subtract the amount of leaf area infected in percent, divided by three, from the total yield. For example, if he estimates that 20% of the leaf area is infected with stripe rust, he would estimate approximately a 7% reduction in yield due to this factor.

If the photo interpreter estimates 20% of the leaf area infected and thus divides this figure by three to obtain the yield reduction factor, an error will result because of his inability to estimate accurately from the photo image the total leaf area infected.

His ability to determine accurately this factor depends on the previously mentioned photo image factors and photo interpretation techniques. In one case it was found that in order for the photo interpreter to judge, by viewing aerial photos, that 20% of the total leaf area was infected there actually had to be at least 60% of the leaf area infected. This is due to the inability of the photo system to record every leaf in the necessary detail. Thus, in the case where 60% of the leaf area was infected, it was not accurate for the photo interpreter to divide by three his estimate of 20% leaf area infected; instead, he should consider 20% directly as the yield reduction. The ground observer's estimate of 60% infected leaf area, however, was divided by three to obtain indirectly a 20% reduction in yield.

This is only one example of the relationships which were developed during the conduct of one of our earlier programs and which were vital to the success of the program. Many correlations must be made to relate the photo interpreter's estimate of the extent and severity of each of these factors to the actual reduction in yield. It has been necessary in some cases to group many of these factors together because of the inability of the system to separate each factor, and subsequently to develop a relationship to yield reduction for these observations.

Because of the relatively low spatial resolution of EREP images, most of the commonly encountered yield-limiting agents (i.e., not of disastrous proportions) are not visible on EREP images. Only in those cases where factors affect whole fields, such as drought or widespread storm damage, will they be revealed by ERTS images. Figures 23-25 show a field in the Marysville test site where poor vigor was detected early in the crop year. The probable cause was improper cultural practices such as herbicide application and water management. This problem was visible on ERTS-1 photos also.

For all but the most severe and widespread crop limiting agents, larger scale images with higher spatial resolution than those possible from EREP are required. These are usually obtainable from aircraft using high resolution camera systems. Thus, the use of a multistage sampling scheme offers a method to evaluate the factors needed in estimating crop yield.

3.6.3 MULTI-IMAGE PHOTO INTERPRETATION

A data reduction technique which has proven to be very useful in increasing the accuracy of yield estimates involves the combining of various crop factor estimates made on photography taken at several dates, and based on photos from several spectral bands. For example, early in the growth of a crop the failure of some plants to become established is visible, thus causing nearly 100% yield reduction in these open areas. At a later date some of the surrounding vegetation may have become lodged or wind-thrown in such a way as to cover and thus obscure from the overhead view these previously bare areas. Therefore, a reduction of yield for

such areas cannot be detected on aerial photos if photography taken at the later date is the only photography available. If early season photography is used for stand establishment estimates and incorporated with later photography, when other factors become visible, a greater accuracy in yield estimates will result.

Multiband photography provides more information to the photo interpreter than does broad single-band photography. When S-192 bands 1 (Blue), 7 (red) and 9 (Near Infrared) are combined in a color additive composite, considerably more information is revealed to the interpreter than when any single band is used.

3.6.4 GROUND TRUTH ACQUISITION

The acquiring of accurate, timely ground truth is an essential part of crop inventory and analysis. Remote sensing data can provide signatures that are consistently recognizable and that correlate with crop production, but it is necessary to have detailed data on the characteristics and components of the various discrete signatures for proper data reduction and synthesis. Ground data are best obtained with photos in hand taken within a few days of the ground visit. It is then possible to correlate more closely the photo images with their true ground counterparts and to relate these data to the reliability of the photograph for crop analysis. In this study ground data collection involved identifying the various crops grown in the test area on a field-by-field basis and determining acreage, planting date, application of fertilizers and herbicides, and data on weeds, pests and other limiting agents. These data were provided by cooperating farmers and by project staff who visited the test sites periodically.

Ground truth for signature identification obtained in one region can be extended to other regions if environmental conditions are similar and where cultural practices, crop varieties, and crop calendars are analogous. However, one should use care in direct application of ground truth outside the area where it was obtained for such factors as effects of various chemical additives and response of crops to pests and diseases in yield estimation. Also, the maximum potential yield of a crop can vary when it is planted in different locations.

Ground truth is obtained most effectively when a sampling procedure is used based on a multistage sampling scheme. In this way it is possible to obtain data that can be used by statistical methods to reflect more nearly the overall crop conditions than if a haphazard approach is used. There will be situations where unusual events occur, such as natural disasters or man-caused events, that will require visits to sites not planned in the sampling scheme to determine the effects, and perhaps the identity, of conditions seen on the photographs or reported by cooperating farmers.

3.7 FACTORS WHICH CONTRIBUTE TO ERRORS IN PHOTO INTERPRETATION AND METHODS OF CONTROLLING THESE FACTORS

3.7.1 CROP CONDITION

As discussed in a previous section, the greatest error in yield estimation by photo interpretation results when numerous yield-limiting factors occur in a crop at the same time. The factors listed

in subsequent sections bear upon the ability of photo interpretation to produce accurate estimates of yield of a crop in any state of health.

3.7.2 FILM/FILTER COMBINATION

The results of this study on rice and some of our earlier investigations conducted on both rice and wheat indicate that it is essential to acquire photography with the proper film/filter combination for detecting each of the yield-limiting factors, and that no single portion of the photographic spectrum can be used for all of the desired identifications. Experience has shown that three bands can be used successfully for crop interpretation. These bands are utilized on Ektachrome Infrared film--green, red and near infrared--and in the multiband system of ERTS-1 and EREP.

3.7.3 PHOTO DATE

Accurate estimates of crop yield are dependent upon the ability of the observer to determine the time during growth of the crop when the yield-limiting influences are operative. Thus, it is essential to specify photographic dates that coincide with periods when the significant yield-limiting influences can be accurately assessed. From such photography one should be able to establish: (1) the approximate date of first attack, and (2) the rate and extent of spread of the damaging agent as the crop develops, under the influence of various environmental factors such as temperature, humidity, and wind. Critical dates in the rice crop calendar for obtaining photography are emergence, pre-heading, full heading and pre-harvest (mature).

3.7.4 PHOTO SCALE

It is apparent from this study, as well as our earlier crop investigations, that use of smaller scales of photography can result in some error in detecting yield-limiting factors and thus in estimating yield by photo interpretation. In some cases, photo enlargement or viewing of film with magnifiers can be performed on small-scale, high resolution photos to permit photo interpretation accuracies very comparable to those obtained from larger photographic scales. Generally, scales of 1:3,000 to 1:5,000 are needed for detailed crop study, and 1:30,000 to 1:60,000 for more general study using aircraft photography. Commonly used aerial cameras provide adequate image detail at these scales.

3.7.5 PHOTO QUALITY

Various factors will limit the quality of the photo image obtained of agricultural crops from either aircraft or spacecraft. These factors include exposure settings, atmospheric conditions, sun angle, camera system resolution, film resolution, filter characteristics, image motion limitations, camera vibration, and photographic processing and printing techniques. Imagery degraded by the existence of less than optimum levels of any of these factors can seriously limit the usefulness of the photographic image for yield estimation by photo interpretation. Thus, it is essential to have reasonably good weather at the time of photography and to employ suitable photographic materials, camera systems, flight parameters, exposure controls, image motion compensations and care in processing and printing techniques.

3.7.6 PHOTO INTERPRETATION TECHNIQUES, REFERENCE MATERIALS AND KEYS

The development of appropriate photo interpretation techniques, reference materials and PI keys is essential if crop condition information

suitable for estimating yield is to be produced by means of photo interpretation. In addition, proper techniques of photo interpretation and proper uses of photo interpretation aids should be taught in special training courses given to those who are to perform operational studies of crop yield in order to assure maximum accuracy of yield estimates made by photo interpretation.

3.7.7 DATA REDUCTION TECHNIQUES

Data obtained from photo interpretation, historical crop information sources, weather observations, and other data sources must be analyzed in a manner suitable for compiling accurate yield estimates. Correlation of photo interpretation yield data with yield data produced by ground observers also must be accomplished.

3.8 VALUE OF HISTORICAL DATA

The acquisition of historical data concerning expected maximum yield from a crop in a particular growing region and the losses generally anticipated from yield-limiting influences such as pests and storm damage will facilitate the making of accurate yield estimates. Such information is essential as a basis for establishing a correlation between image factors and crop condition. The data should be updated from season to season as new varieties are introduced, and new growing techniques are applied (including application of herbicides, fungicides, pesticides, and chemical nutrients).

3.9 SUMMARY OF REQUIREMENTS FOR USEFUL YIELD ESTIMATES

In order to estimate yield of a rice crop, it is essential to detect the occurrence of various limiting factors which tend to reduce the vigor (and thus the yield) of plants during the growing cycle.

Vigor reduction can be in the form of retarding of growth caused by various factors such as cool temperature, drought, disease, insect damage, improper water management, mechanical damage, improper chemical application, or insufficient mineral nutrition. Various degrees of each of these factors may occur depending upon the plant's ability to tolerate conditions of environment and due to cultural practices in crop production.

Useful yield estimates usually require:

a. Multiband photography in spectral zones typical of Ektachrome infrared film.

b. Proper scheduling of sequential photo coverage.

c. Historical data regarding crop yield and growing conditions.

d. Suitable photo interpretation reference materials and keys.

e. Adequate training of photo interpretation personnel.

f. Appropriate data reduction techniques.

3.9.1 RECOMMENDED PHOTO DATES

a. For determining plant density: 30 to 45 days after planting.

b. For determining seedling survival: 30 to 45 days after planting.

c. For detecting soil toxicity and assessing mineral nutrition: 30 to 60 days after planting.

d. For estimating disease damage: 60 to 100 days after planting.

e. For estimating weed infestation damage: 60 to 100 days after planting.

f. For estimating wind lodging damage: 90 days after planting to harvest.

g. For determining time of heading: depends upon variety (generally 75 to 100 days after planting).

h. For making the final pre-harvest analysis: one to two weeks before harvest.

3.10 RESULTS OF PHOTO INTERPRETATION TESTS FOR VEGETATION COMPLEX IDENTIFICATION[1]

A series of photo interpretation tests were conducted to compare the results obtained using several image types from ERTS-1 MSS and Skylab EREP systems. The evaluation was based on these test films' usefulness for identifying land use and agricultural crops, and for assessing crop condition and vigor--all factors necessary for yield estimation. The following sections define the results of the previously

[1]A Comparison of Skylab and ERTS Data for Agricultural and Natural Vegetation Interpretation, Technical Report, July 1, 1974, Earth Satellite Corporation. NASA Contract No. NAS 9-13286.

cited photo interpretation tests using 40 photo interpreters responding to prepared test materials.

3.10.1 AGRICULTURAL CROPS

Crop Identification--Late Summer Seasonal State

For the identification of agricultural crops at the late summer seasonal state, the EREP S-190A color IR and the ERTS color composite images were significantly different from (and better than) all the other image types. For the test region studied, the spectral differentiation afforded by the color infrared medium is more useful for crop type discrimination than is the sharper resolution of the EREP S-190A and S-190B color images. Since all agricultural fields selected as test and training examples were well above the minimum detectable field size, little added information regarding crop type was derived from sharper image detail. For this reason ERTS imagery was essentially as useful in all bands, and in color combinations, as the EREP counterpart. This fact is considered of great importance in the context of the present study because of the potentially greater speed, after acquisition, with which the ERTS imagery can be made available to the analyst.

All four color images ranked higher than the black-and-white images for crop identification. Image ranking is summarized below:

Image Type	Overall Average Correct Responses (all crop categories)[1]
EREP S-190A Color IR	7.5
ERTS Color Composite	7.4
EREP S-190B Color	6.8
EREP S-190A Color	6.7
EREP S-190A B/W IR	6.6
ERTS Band 7	6.4
EREP S-190A B/W Red	6.0
ERTS Band 5	5.5

Crop Identification--Late Spring Seasonal State

The EREP S-190A color and color IR images again were significantly better than the other image types for crop identification at the late spring seasonal state. All three color images ranked higher than the black-and-white images. Image ranking is summarized below:

Image Type	Overall Average Correct Responses (all crop categories)[1]
EREP S-190A Color	7.1
EREP S-190A Color IR	7.0
ERTS Color Composite	6.1
ERTS Band 5	5.9
EREP S-190A B/W Red	5.8
ERTS Band 7	5.6
EREP S-190A B/W IR	5.4

Crop Identification--Seasonal Comparisons

Overall interpretation results for both image dates were very similar; only for the identification of specific crops can one date be

[1]Maximum possible = 10

recommended over another. (While not investigated by formal testing, it is probable that multidate imagery would permit more accurate crop identification to be made than would be possible on single date imagery.)

In both cases, all the color images ranked higher as a group than the black-and-white images. For the late summer seasonal state, the EREP S-190A color IR and ERTS color composite were better than the other types; for the late spring seasonal state, the EREP S-190A color IR and color images were best. The numerical rankings of the remaining images were not significantly different; hence, it is impractical to attempt to specify a composite ranking for interpretation at the two seasonal states.

The utility of additive color enhancement techniques for displaying (1) the regional extent of, and (2) changes in areas devoted to rice culture over a two-year period was demonstrated with ERTS imagery.

Land Use Identification and Delineation

The combination of high resolution and spectral discrimination afforded by the EREP color images results in the highest subjective estimate of accuracy for land use identification and delineation. Whereas crop identification *per se* is accomplished most accurately on color infrared (EREP) or color infrared simulations (ERTS), the identification of land use categories frequently depends upon the detection of image pattern or detail as well as a unique image signature (e.g., urban areas are characterized by regular street patterns, and dryland pasture has a unique texture and pattern). Ranking of image type according to total certainty ranking is as follows, best image appearing first:

Image Type	Total Certainty Ranking[1]
EREP S-190B Color	8
EREP S-190A Color	11
EREP S-190A Color	14
ERTS Color Composite	15
EREP S-190A B/W Red	16
EREP S-190A B/W IR	19
ERTS Band 7	20
ERTS Band 5	22

3.10.2 COMBINED RANKING FOR AGRICULTURAL CROP AND NATURAL VEGETATION IDENTIFICATION

All eight image types tested have been ranked according to the overall mean correct identification. The ranking of each image type was identical on both tests with one exception (from best to worst)[2]:

EREP S-190A Color IR
ERTS Color Composite
EREP S-190B Color
EREP S-190A Color
EREP S-190A B/W IR
ERTS Band 7
EREP S-190A Red
ERTS Band 5

These results indicate that, for the vegetation complexes interpreted, and for the relatively large areas occupied by each test item, the spectral information from a color infrared image or ERTS color infrared simulation is more valuable than increased resolution provided by EREP color (S-190A and S-190B) images.

[1]6 = Certain ranking for all categories

[2]The EREP S-190A color image ranked lower for natural vegetation than for agricultural crops. However, it was predicted that the poor color quality of the test print (only for the Colorado Plateau Test Region) might affect its interpretability for natural vegetation types. Its composite ranking here is assigned on the basis of the agricultural crop test results only.

3.11 RESULTS OF PHOTO INTERPRETATION TESTS FOR VEGETATION COMPLEX IDENTIFICATION

3.11.1 AGRICULTURAL CROPS

Minimum Field Size

Minimum field size consistently detectable is directly related to image resolution for targets of both high and low contrast. The image types can be ranked as follows (no statistical significance associated with order):

Image Type	Minimum Field Size (Acres) High Contrast	Minimum Field Size (Acres) Low Contrast
EREP S-190B Color (high res.)	3-5	5-8
EREP S-190A Color	3-5	5-8
EREP S-190A B/W Red	3-5	5-10
EREP S-190A Color IR	8-12	12-17
EREP S-190A B/W IR	8-12	30-40
ERTS Color Composite	10-15	20-30
ERTS Band 5	10-20	30-40
ERTS Band 7	10-20	30-40

Rice Crop Delineation

Both the ERTS color composite and EREP S-190A color IR images produced highly accurate delineations of a rice growing region. Commission errors were also minimal, indicating that the early summer season is an appropriate time of year for separating rice growing from non-rice growing areas. Using the ERTS color composite, 90.7% of the rice growing area was correctly identified; the accuracy obtained with the EREP S-190A color IR image was 82.1%.

3.12 RESULTS OF PHOTO INTERPRETATION TESTS FOR EVALUATING VEGETATION VIGOR AND CONDITION OF AGRICULTURAL CROPS

Either of the systems tested, EREP or ERTS, has adequate spatial resolution for regional agricultural crop survey purposes. Such surveys usually do not require absolute identification of the crop type in every field throughout the region.

For more detailed agricultural surveys, however, such as those used by farm managers, market analysts and tax assessment officials, ERTS data do not provide adequate image spatial resolution for such uses.

EREP S-190A will provide adequate images for some management applications but, as with ERTS images, usually not those requiring local decisions related to plant vigor and stress, such as weed and pest control or soil additives (nitrogen, minerals, etc.).

EREP S-190B, on the other hand, provides improved resolution over the other systems and, when used under favorable atmospheric conditions (clear skies--minimum haze), can be applied by farm managers to make some on-site decisions regarding field practices, particularly for fields of five acres or larger in size.

The high resolution afforded by a system such as the EREP S-190B camera is essential for detection of such yield-reducing factors as lodging which have sharp, well-defined boundaries and contrast sharply with the surroundings. Lodging patterns could be frequently confirmed only on the EREP S-190B color image. The high spatial resolution

of this system is much more critical for lodging recognition than is the spectral detail of the particular film type used in it. In no cases was it possible to detect lodged rice fields on ERTS imagery because of the relatively poorer spatial resolution.

Because color infrared images provided the most useful data in this study for crop identification and evaluation, it is recommended that color infrared film (or the bands that comprise that film as in ERTS-1) be specified for systems such as the EREP S-190B or the ERTS MSS when used for crop monitoring applications. This recommendation is justified even though only color film from the S-190B system was available for testing in this study.

The frequency of timing of coverage for regional crop surveys and farm management practices is difficult to specify precisely because of the uncertainty of the occurrence of certain critical environmental events which may alter an otherwise "normal" season. These factors include such events as drought, frost damage, excessive precipitation and wind storms. As noted earlier, some agricultural areas are more prone to unfavorable weather conditions for remote sensing coverage and thus may be difficult to cover with any inflexible schedule. One factor is certain, however, and that relates to the delay in receipt of images once they have been exposed. For regional surveys a delay of several weeks may be acceptable to the agricultural analyst. For the market analyst and the farm manager remote sensing images are a perishable item and a delay of more than a few days can render the images almost useless for making current management decisions because of the irreversability of some crop problems if action to counteract a faulty condition is not taken promptly.

Experience with both ERTS and EREP by the investigators indicates that data from both systems were not available in time to be applicable to market analysis or farm management and only marginally useful for regional agricultural analysis. In the future, however, it should be possible to make available promptly to the image analyst (i.e., on a near real-time basis), ERTS-1 data of those agricultural areas that are of greatest interest to him even though this ordinarily would not be possible for EREP-type data.

3.13 IMAGE QUALITY CONSIDERATIONS

Usually image analysis, as performed by humans rather than machines, is done from a study of opaque prints, either color or black-and-white. In such instances the photo quality of the prints can significantly affect the interpretability of many features, particularly where tonal contrasts and feature sizes are at or near the threshold of detectability. It is, therefore, important to produce photos for visual interpretation with great care and to ensure that information is not lost in the photo reproduction phase to any significant degree.

Multidate images can provide improved detectability of vegetation types by exploiting the differences in target reflectances as seasonal changes occur (crop calendar characteristics). However, the photo systems tested did not show any inter-system differences in usefulness for the problems studied related to the multidate approach although we only evaluated two dates of Skylab data and seven dates of ERTS imagery for this determination.

3.14 UNRESOLVED PROBLEMS

Time and funds were not available for this project to permit complete and intensive evaluation of all images for use in yield analysis. The factors that have been shown in past studies to be necessary for evaluating yield potential of rice crops were studied and the suitability of the several image types available were analyzed.

In some cases the relative usefulness of a particular image for a particular application was determined by photo interpretation tests and in other cases specific judgments were made by photo interpretation methods by remote sensing experts. Where appropriate these findings were reported in the report.

In order for a final evaluation to be made regarding the usefulness of each image type, spectral band and date of photography (e.g., for rice yield analysis and for specific parcels) considerably more photo interpretation time would be required. From the data that were evaluated, it was apparent that a combination of image types (multiband, multidate, multistage, multi-enhanced, etc.) would provide more information of the types dealt with in this study than could be obtained from any one type.

Several factors contributed to the difficulties in a full evaluation of yield-estimating techniques and therefore left unresolved problems. An adequate multidate series of photos was not obtained during the rice growing season from the Skylab spacecraft because of scheduling problems in data passes, weather problems over the Louisiana test area, and spacecraft equipment problems. The data received

did not cover the times in the crop calendar when a true test could be made of the yield estimation potential of Skylab data.

A major problem that remains unresolved is the question of the specific needs of the agricultural user regarding data format, spectral and spatial discrimination (resolution) considerations for various user applications, frequency of coverage in relation to the above questions, user data interpretation needs, and time constraints for receipt of data that are required for the various agricultural users.

Neither time nor funding were provided in this investigation to answer the question of user requirements regarding data and equipment needed by the various agricultural users of information from remote sensing satellites and aircraft.

It is apparent that a very intensive effort must be mounted to provide the user with assistance in data acquisition, interpretation and decision making from the remotely sensed data in order to realize fully the potential from satellite and supporting aircraft imagery. The assistance provided by the EROS Data Center and its outlying offices is a start in the right direction but an extension service type organization provided by a combination of government, universities, and private industry is needed to fill a very large gap between the available information in "raw" remotely sensed data and the finished data for use in the decision making process that is ultimately required. This service must be dispersed in the growing regions and the technical and economic levels must be compatible with the user's ability to apply cultural practices in response to data produced.

4.0 AUTHOR IDENTIFIED SIGNIFICANT RESULTS

4.1 NATURAL VEGETATION ANALOGS

For interpreting a wide range of natural vegetation analogs, S-190A color infrared and the ERTS-1 color composite were consistently more useful than were conventional color or black-and-white photos. For identifying the vegetation complexes, these two films were significantly better, with S-190B color running a close third. Black-and-white infrared imagery from the S-190A system ranked very close to the S-190B color image. The red band black-and-white photo was poorest of all.

Color infrared was superior for five vegetation analogs while color was superior for only three. The errors in identification appeared to be associated more with black-and-white single-band images than with multi-band color. There was further indication that spectral discrimination was more important than spatial resolution for these interpretations because of the inconclusive findings regarding images with varying spatial resolution, particularly for vegetation analogs that were above a minimum threshold size.

The results of our testing and accumulated experience indicate that the best single seasons for imaging natural vegetation with color infrared is as the vegetation types of interest are moving into the dry or mature growth period. The interpretability for identification purposes is nearly always low during the season of peak vegetative growth (late spring and early summer). It should be noted however, that multidate imaging provides the only means for consistent identification of some vegetation complexes because of the similarity in appearance of associated types in the natural scene at specific dates.

For mapping vegetation boundaries, the higher spatial resolution color materials obtained from Skylab (S-190A and B) provided better scores for boundary delineation than did the lower spatial resolution materials tested (ERTS color composite and S-192 color composite). However, these lower spatial resolution systems provided the highest percentage of "pure types" for vegetation delineation because of the higher level of generalization inherent in the poorer spatial resolution with regards to the image used and season of acquisition. The number of delineations per 2,000 square kilometers is also an index of information content when mapping is done under the same standards. This factor tends to place S-190B color at the top, followed by S-190A color and color infrared, ERTS-1, and S-192, respectively.

In considering the costs to produce meaningful information from the images tested, we derived the following scale assuming that the number of delineations per 2,000 square kilometers is an index of information content.

Image Type	Ratio
S-190B Color	0.50
ERTS-1 Color Composite	0.43
S-190A Color Infrared	0.42
S-192 Color	0.30
S-190A Color	0.30

An investigation of the use of Skylab stereoscopic versus monoscopic photographs, for identification of vegetation complexes, indicated that experienced interpreters were able to identify specific vegetation types more accurately for all categories except one. This category--sedge meadow--always occurs in very small units and was sometimes difficult to see on the stereo model.

There was also a marked improvement in boundary delineation when using stereoscopic photographs from Skylab, particularly where changes in terrain relief were related to changes in vegetation types--a common occurrence in wildland vegetation communities.

4.2 RICE CROP ANALOGS

The test and evaluations conducted in this investigation, while limited in scope, have provided information on the usefulness of spacecraft remote sensing data for agricultural crop identification, field area measurement, and detectability of stress and crop vigor conditions. These findings are as follows:

1. Spectral discrimination (commonly referring to the spectral bandwidth and numbers of bands exploited by any remote sensing system) and spatial discrimination (commonly referring to the level of detail visible on a remote sensing image expressed as minimum feature size visible on the ground or as number of pairs of black-and-white lines visible per millimeter on a photo image) both contribute to the usefulness of images for data collection. In the investigation performed here errors in crop identification occurred where space images with both relatively higher spatial and spectral discrimination were tested. For those features above the minimum field size of interest (perhaps 20 acres) resolvable on all images tested, spectral discrimination is highly important as evidenced by test results. The S-192 color composite photo of Louisiana provided a higher accuracy score than did the S-190A or S-190B images taken at the same time. (The S-192 had a higher spectral discrimination than either S-190A or S-190B, and the reverse is true for spatial discrimination).

In order for spatial discrimination to emerge as being critical or limiting, two considerations applied. If either minimum field size desired required higher spatial discrimination, or if a need to observe crop features in great detail required it, then spatial discrimination was of greater importance than spectral discrimination. For example, if the interpreter was asked to map and identify all rice fields to a minimum 2 acre field size, he could not achieve that objective using any of the space images tested in this study. He would need aerial photos with a higher spatial discrimination to be able to resolve fields of the 2 acre minimum size. Both the NASA high-flight photos (scale 1:65,000) and the aerial photos taken by project staff (1:30,000) were useful for that determination. It should be emphasized that for photo interpretation, spectral and spatial discrimination are inversely interrelated in that as one is degraded the other must be upgraded to maintain the same level of image usefulness for a given problem. We did not have enough imagery covering a range of spectral and spatial discrimination characteristics to establish the levels of each for all agricultural monitoring tasks.

2. The Skylab EREP system did not provide photos within a time frame that would permit them to be used for making management decisions regarding such factors as seeding, irrigation, agricultural chemical application, or harvest. While it is recognized that no effort was planned to have such rapid access to the data obtained by the astronauts from earth orbit, the delays inherent in processing and distributing the raw data to a variety of users in widespread locations greatly limits its usefulness for day-to-day agricultural crop management decisions.

Since there is a need for repeated photo coverage at specified times if the images are to be useful for crop monitoring, the problem of data processing and distribution becomes a very real and perpetual consideration in utilizing hard copy film recoverable from space for this application. This problem becomes very sizeable if global land areas are to be covered on a repetitive basis. A more plausible approach would appear to be the use of an ERTS type system with relatively lower spatial resolution with broad area coverage in a telemetered mode for repeated monitoring, and a high spatial resolution system such as that available from a recoverable film satellite that is used in a pointable spot sampling mode. When both systems are available and can be controlled for a programmed crop survey application, the advantages of each can be exploited. In such a program there would be many situations where supporting aircraft coverage would be the most efficient and perhaps the most certain way of obtaining necessary crop monitoring data. Such a situation would apply in those study areas where persistent cloud cover restricts the periods of clear photographic weather, thus causing problems in obtaining coverage from a satellite with rigidly timed overpasses. Aircraft would be used to take photos of spot locations during short periods of breaks in cloud cover.

Our experience in obtaining coverage of the Louisiana Coastal Plain Test region illustrates this situation very clearly. We obtained only very limited amounts of satellite data because of cloud cover but by use of project aircraft were able to obtain coverage at all critical crop stages of selected sample points.

3. Tests and subjective analyses conducted in this study indicated that the spectral bands exploited in color infrared film were the most useful for agricultural crop analysis. The S-192 system included those bands as did the ERTS-1 satellite.

4. Accuracy of crop identification on any single date of Skylab images will be less than that of multidate analysis due to differences in crop calendar, cultural practices used, rice variety, planting date, planting method, water use, fertilization, disease, or mechanical problems, etc.

5. It is evident that accuracy of rice field identification will be high using a combination of photographs taken at three specific periods:

(a) At the time soil has been prepared prior to flooding

(b) At the time fields are flooded

(c) At the time vegetation fully covers the water.

Thus, one of the major keys in the phenological progression of rice (crop calendar) which separates it from the other crops is the transition from the totally flooded to the totally vegetated condition.

6. Mapping and acreage determinations on individual fields made directly from Skylab imagery without the use of supporting aircraft photos are difficult due to spatial resolution and physical field size problems. It is not possible to recognize and delineate most non-cropped areas (drain ditches, roads, storage yards, pumps, etc.) found within rice fields on the S-190A and S-192 photographic images. If direct

mapping and acreage determination are to be accomplished, acreage reduction factors to correct for included, non-cropped area must be determined for each rice growing region. This acreage correction can be made using support aerial photography and to a lesser degree S-190B photographs.

5.0 RECOMMENDATIONS

As noted in the report, we were not able to perform a simulated operational photo interpretation exercise to predict yield on either the California or Louisiana rice crop test areas. In California delays in receiving Skylab and high-flight support imagery prevented any real-time evaluation of the imagery for those areas not covered by our support aerial photography. However, in those areas where we have coverage from Skylab, ERTS-1, high-flight and low-flight support photos, we were able to determine that the factors that must be monitored and quantitatively evaluated for rice yield estimation are interpretable consistently and predictably. From these observations we make the recommendation that a study be performed in the Northern Great Valley to map the acreage where rice is grown and to estimate the anticipated production by use of sequential photo coverage from satellite (Skylab and ERTS-type) systems supported by photos from a high- or low-flight aircraft in a multistage sampling scheme for a full rice growing season running from April 1 to October 15.

Furthermore, an investigation should be conducted which utilizes the S-192 digital tapes to generate data by computer readout for such factors as crop identification and acreage determination and utilizes a combination of visual and computer readout for evaluating plant vigor and stress. Such an evaluation could be conducted on existing S-192 data for parts of the United States where data are available.

As noted, the coverage received of the Louisiana Coastal Plain Test region was not adequate to permit an evaluation of the methods

devised because of persistent weather problems, as well as limited data passes at desired times. It therefore is recommended that a study be done to determine what spacing of sequential coverage would be needed to provide adequate photo coverage (at least once every 18 days) over the Louisiana rice crop areas in a typical year in order to overcome weather problems. From these data it would be possible to determine the frequency of satellite overpasses that would be needed in order to assess the rice crop in Louisiana by a sun-synchronous satellite system.

Appendix A

HIERARCHICAL LEGEND AND FORMAT

Table A1. Analogs Represented in Test Regions
(+ = well represented with useable examples;
x = poorly represented, marginally useful examples)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
100-700	All primary classes	+	+
100	Barren Land	+	+
110	Playas	+	x
120	Aeolian barrens	x	+
130	Rocklands	+	+
150	Badlands	x	x
160	Slicks	+	
180	Man-made barrens	x	x
200	Water Resources	+	+
210	Ponds, lakes, and reservoirs	+	+
220	Water courses	x	x
280	Snow/Ice	+	+
300	Natural Vegetation	+	+
310	Herbaceous types	+	+
312	Annual types (mostly *Bromus tectorum* L.)	+	+
313	Forb types (Broad-leaved, herbs dominant)	x	x
314	Steppe, grassland, and prairie	+	x
315	Meadows	+	+
315.1	Sedge and sedge-grass meadows	+	+
320	Shrub/scrub types	+	+
324	Halophytic shrub types	+	+

Table A1 (cont'd.)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
324.1	Greasewood types (Sarcobatus vermiculatus (Hook.) Torr.)	+	+
324.2	Saltbush types (Atriplex nuttallii Wats., A. confertifolia (Torr. and Frem.) Wats., A. obovata Mog.)	x	+
324.3	Shadscale/Budsage types (Atriplex confertifolia-Artemisia spinescens Eat.)	+	+
324.4	Bailey's greasewood (S. baileyi Cov.)	+	
324.5	Blackbrush types (Coleogyne ramosissima Torr.)		+
325	Shrub steppe types	+	+
325.1	Sagebrush types (Artemisia spp.)	+	+
325.2	Sagebrush-Bitterbrush types (A. tridentata Nutt.-Purshia tridentata (Pursh) D.C.)	+	x
325.3	Bitterbrush types	x	x
326	Sclerophyllous shrub	+	x
326.1	Manzanita chaparral (Arctostaphylos spp.)	+	x
326.2	Oakbrush chaparral (Sclerophyllous-Evergreen Quercus spp.)	+	
326.3	Snowbrush (Ceanothus velutinus Dougl.)	+	+
326.4	Chamise (Adenostema fasciculata H. & A.)	+	
326.5	Curlleaf Mountain Mahogany (Cercocarpus ledifolius Nutt.)	x	x
327	Macrophyllous shrub	+	+
327.1	Oakbrush chaparral (Q. gambelii Nutt.)	+	
327.2	Mountain brush, Serviceberry-Snowberry-Birch leaf Mountain Mahogany (Amelanchier spp.-Symphoricarpos spp.-Ceanothus montanus)	+	+

Table A1 (cont'd.)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
327.3	Willow (_Salix_ spp.)	+	+
330	Savanna-like Types	+	+
336.1	Pinyon (_Pinus_ spp.)-Juniper (_Juniperus_ ssp.)-Shrub Savanna	+	+
340	Forest and Woodland Types		
341	Conifer forests	+	+
341.1	Juniper or Pinyon-Juniper (_Pinus monophylla_ Torr. and Frem. or _P. edulis_ Engelm., _Juniperus osteosperma_ (Torr.) Little)	+	+
341.2	Ponderosa or Jeffrey pine forests (_Pinus ponderosa_ Dougl.., _P. jeffreyi_ Grev. and Balf.)	+	+
341.3	Mixed conifer forests (Pine-Douglas fir-true fir-Hemlock) (Pinus-Pseudotsuga-Abies-Tsuga)	+	+
341.4	Spruce-fir forests (_Picea engelmannii_ Parry ex Engelm, Abies lasiocarpa)	+	+
341.5	Lodgepole pine forests (_Pinus contorta_ Dougl.)	+	+
342	Broadleaf forests	+	+
342.1	Deciduous oak woodlands (_Quercus kelloggii_ Hewb.)	+	x
342.2	Evergreen oak woodlands	+	-
342.3	Bottomland cottonwood (_Populus wizlizenii_ (Wats.) Sarg.)	+	+
342.4	Aspen types (_Populus tremuloides_ Michx.)	+ x	+
343	Conifer-hardwood forests	+	+
343.1	Aspen-spruce-fir forests	-	+

Table A1 (concluded)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
343.2	Pine-oak forests	+	-
414.0	Cleared juniper rangeland, seeded to grass	+	+
425.1	Cleared juniper rangeland, sagebrush understory	+	+
500	Agricultural cropland	+	+
600	Urban and industrial lands	+	+
700	Extractive industry	x	x

Table A2. Mapping Classes and Format for the Annotation and Description of Land Surface Characteristics

Macrorelief Landform Degree of Dissection Slope Class* Microrelief*

X.XXXXX

MACRORELIEF:

1. = Flatlands

2. = Undulating to rolling lands

3. = Hilly lands

4. = Mountainous lands

LANDFORMS:

.10 = Depressional, non-riparian

.11 = Basins (interior drainage, usually with playas or lakes)

.12 = Basins, calderas

.13 = Peneplanes

.20 = Bottomlands, riparian

.21 = Stringer or narrow river and stream bottomlands and limited terraces

.22 = Wide river bottomlands with floodplain and terraces

.23 = Depressional drainage ways

.24 = Desert wash

*These two levels are generally appropriate to use only with intensive large-scale inventories at scale of about 1:25,000 and larger.

Table A2 (cont'd.)

.30 = Planar surfaces (upland, above classes X.1 and X.2)

.31 = Valley fill (down slope erosional)

.32 = Fans and bajadas

.33 = Lake or marine terraces

.34 = Pediments

.35 = Flat to strongly undulating plateaus, mesas, benches, and broad ridgetops

.36 = Flat to strongly undulating dip slopes

.XX1 = Smooth, undissected

.XX2 = Moderately dissected

.XX3 = Strongly dissected - secondary erosional cycle

.40 = Slope Systems (vegetation and soils tend to change with slope)

.41 = Escarpments

.42 = Valley or canyon slope systems (the valley floor falls in X.3 class). Tertiary levels based on drainage pattern.

.43 = Strongly undulating to rolling uplands

.44 = Butte and isolated hill slope systems

.45 = Hill and mountain, more or less angular slope systems. Tertiary levels based on drainage pattern.

.000X* = Exposed (1), or protected (2)

Table A2 (cont'd.)

MICRORELIEF:*

.XXXX1	= Convex
.XXXX2	= Concave
.XXXX3	= Ridge and swale
.XXXX4	= Mounded
.XXXX5	= Pitted/slumped
.XXXX6	= Patterned ground
.XXXX7	= Badlands

SLOPE CLASSES:*

Slope Range %	Slope Class Digit
Simple Slope Systems	
0 - 5	.XXX1
5+ - 15	.XXX2
15+ - 30	.XXX3
30+ - 50	.XXX4
50+ -100	.XXX5
100	.XXX6
Complex Slope Systems	
0 - 30	.XXX7
0 - 50	.XXX8
30 -100+	.XXX9

*Generally used only on intensive inventories done at scales of 1:25,000 and larger.

Appendix B

FORMAL TESTING OBJECTIVES AND PROCEDURES

1.0 QUANTITATIVE TEST OBJECTIVES

The specific objectives of the quantitative agricultural crop and natural vegetation tests, respectively, were as follows:

1.1 AGRICULTURAL CROP TESTS

Test 1: To determine the relative crop identification accuracy achieved with eight types of ERTS and EREP imagery acquired at one seasonal state (late summer) for one agricultural area (Northern Great Valley of California).

Test 2: To determine the relative crop identification accuracy achieved with seven types of ERTS and EREP imagery acquired at a different seasonal state (late spring) for a portion of the same geographic area as selected for Test 1. The value of each season (late spring and late summer) for crop identification was also assessed.

Test 3: To determine the relative accuracy of ERTS color composite imagery and EREP S-190A IR color photography for stratification (delineation) of rice-growing regions within selected portions of the Northern Great Valley Test Region (late spring seasonal state).

1.2 NATURAL VEGETATION TESTS

Test 4: To determine the relative accuracy of identification of natural vegetation types achieved with eight types of ERTS and EREP imagery acquired at one seasonal state (summer) for one wildland area (Colorado Plateau).

Test 5: To determine the value of stereoscopic viewing for identification of natural vegetation types using one type of EREP imagery (S-190A color IR).

1.3 PHOTO INTERPRETATION TESTING OF S-192 DATA RECEIVED AFTER INITIAL TESTS

The S-192 (channels 1, 7, and 9--color composite images, blue, far red, and near infrared) of the agricultural test regions were not available for the initial testing on this project and were therefore evaluated in a second series of tests. In addition to the S-192 data of California and Louisiana rice study areas, we tested S-190A and S-190B color photos of the Louisiana rice crop area. The corresponding Louisiana S-190A color infrared photos were grossly overexposed and unuseable in the testing phase. (See Table B1).

Two groups of 5 students from a University of California remote sensing course were employed for these photo interpretation tests.

Photographs were enlarged in color transparency form from the Skylab photos provided by NASA to a scale of about 1:100,000 for testing purposes. Where ground truth was available we selected specific fields (7 in Louisiana and 10 in California of each agricultural type) representing typical crop types and marked those fields for identification by the interpreters. A series of training fields were also marked for comparison by the interpreters in the testing phase.

The responses were then scored and the results analyzed.

2.0 QUANTITATIVE TEST PROCEDURES

2.1 IMAGE FORMAT

Preliminary tests were made by EarthSat personnel to establish the fact that enlarged positive prints were essentially as interpretable as

Table B1. Image Type Codes for Agricultural Photo Interpretation Testing

Number of Identified Agricultural Types	Replications of Each Agricultural Type	Test Identifications	System/Film	Date	Area
4	7	28	S-190B/Color	8-4-73	Louisiana
4	7	28	S-190A/Color	8-4-73	Louisiana
4	7	28	S-192/Color Composite (Channels 1, 7, 9)*	8-4-73	Louisiana
6	10	60	S-192/Color Composite (Channels 1, 7, 9)*	9-12-73	Sutter and Marysville, Ca.

*Channel	Spectral Band (Microns)
1	.375 - .405
7	.720 - .760
9	.820 - .880

positive transparencies. Consequently it was decided to administer the interpretation tests using enlarged positive prints for the following two reasons:

1. At least five copies of each image were needed so that each section of five interpreters (from a group of 20) could interpret the same image at the same time.

2. Substantial image enlargement was required so that test items could be annotated without confusion and interpretation could proceed without providing each interpreter with high-powered magnification capability.

All formal photo interpretation testing was accomplished using the imagery in a positive print form (1:150,000 scale for the Northern Great Valley area; 1:500,000 scale for the Colorado Plateau area). These prints were made from copy negatives produced from the positive transparencies sent to the investigators for their ERTS and EREP experiments. Of the black-and-white negatives received, only the EREP negatives were of sufficient quality to permit direct enlargement (printing) from them. ERTS black-and-white negatives were too dense; the positive transparencies were used as the image source instead, with copy negatives made as the interim step to obtain positive prints.

Much of the subjective (non-testing) analysis was undertaken with the positive transparencies in order that unnecessary variation in photographic characteristics could be avoided. Since the subjective analysis was undertaken by only one or two individuals at a time, it was feasible to work directly with the positive transparencies under magnification.

The most critical operational problem in testing was the achievement of consistent and uniform color balance among the prints compared. For the Northern Great Valley Test Region a set of test images of uniform quality was used. Although slight variation in image scale did occur for some of the images, this was judged not to affect the image signatures of the test categories.

Comparative color balance on the two members of the stereo model used in the natural vegetation test was excellent. Among the color prints used in the monocular natural vegetation test, the EREP S-190A color image was undesirably dark in the entire forested area, thus probably detracting from the quality of interpretation of the forest types with this film/filter combination. The EREP S-190A color infrared image had good color balance and matched rather well the color balance of the frame used for the stereo testing. The EREP S-190B color image had good color differentiation throughout. The ERTS color composite image was reconstituted from bands 5 and 7 only. These were the only bands available for the required date. It was a rather good quality color product, although it did not contain the typical color signatures to which most experienced interpreters of ERTS color composites made from bands 4, 5 and 7 would have been accustomed. Since the training sets were individually identified for each of the film/filter types, this was judged not to be a problem in the evaluation.

2.1.1 GENERAL METHODOLOGY

The design and implementation of each test was similar. Therefore, a description of the procedures used for Test 1 will be presented in detail. The specifics of each of the other tests are outlined in Table B2.

Table B2. Summary of ERTS/EREP Image Interpretation Tests

TEST NUMBER	TEST OBJECTIVE	TEST AREA	NUMBER OF PHOTO INTERPRETERS	IMAGE TYPES	TEST CATEGORIES/NUMBER OF TEST ITEMS PER CATEGORY	TOTAL PI RESPONSES PER CATEGORY PER IMAGE TYPE
1	Agricultural Crop Identification (late summer seasonal state)	Sacramento Valley, CA (Marysville and Sutter Sites)	40	ERTS Band 5 ERTS Band 7 ERTS Color Composite SKYLAB 190A B/W (red) SKYLAB 190A B/W (IR) SKYLAB 190A Color SKYLAB 190A Color IR SKYLAB 190A High Res. Color	R (rice)/10 O (orchard)/10 A (alfalfa)/10 F (fallow)/10 G (dryland pasture)/10 X (other agric. crops)/10	400 400 400 400 400 400
2	Agricultural Crop Identification (late spring seasonal state)	Sacramento Valley, CA (Marysville Site)	10	ERTS Band 5 ERTS Band 7 ERTS Color Composite SKYLAB 190A B/W (red) SKYLAB 190A B/W (IR) SKYLAB 190A Color SKYLAB 190A Color IR	R (rice)/6 O (orchard)/7 A (alfalfa)/6 F (fallow)/3 G (dryland pasture)/7 X (other agric. crops)/3	60 70 60 30 70 30
3	Stratification of Rice-Growing Region (late spring seasonal state)	Sacramento Valley, CA (Marysville Site)	10	ERTS Color Composite SKYLAB S190A Color IR	Rice, non-rice; 2 outlined test areas for delineation - total area = 17 sq. mi.	20 delineated test areas
4	Natural Vegetation Type Identification (summer seasonal state)	Colorado Plateau	40	ERTS Band 5 ERTS Band 7 ERTS Color Composite SKYLAB 190A B/W (red) SKYLAB 190A B/W (IR) SKYLAB 190A Color SKYLAB 190A Color IR SKYLAB 190B High Res. Color	J (pinyon-juniper woodland)/10 P (ponderosa pine forest)/10 W (sedge (wet) meadow)/10 A (aspen forest)/10 S (spruce-fir forest)/10 X (other vegetation types)/10	400 400 400 400 400 400
5	Value of Stereoscopic Viewing for Natural Vegetation Type Identification (summer seasonal state)	Colorado Plateau	10	SKYLAB 190A Color IR	J (pinyon-juniper woodland)/10 P (ponderosa pine forest)/10 W (sedge (wet) meadow)/10 A (aspen forest)/10 S (spruce-fir forest)/10 X (other vegetation types)/10	100 100 100 100 100 100

Test 1 Objective: To determine the relative identification accuracy for agricultural crops achieved using eight types of ERTS and EREP imagery for one seasonal state (late summer) for one agricultural area (Northern Great Valley, California).

Agricultural Crop Categories:

R - rice

O - orchard

A - alfalfa

F - fallow

G - dryland pasture (grass)

X - other agricultural crops

Image Types (positive prints, approximate scale = 1:150,000):

B/W:
1. ERTS MSS Band 5
2. ERTS MSS Band 7
3. S-190A (red)
4. S-190A (infrared)

COLOR:
5. ERTS Color Composite
6. S-190A Color
7. S-190A Color Infrared
8. S-190B (high resolution)

Test Format (each test item marked by an annotated dot on an acetate image overlay:

Training examples: 2 per test category per image type

Test items: 10 per category per image type (= 60 per image type)

Time for interpretation: approximately 5 minutes per image type for training; 30 seconds per test item (30 minutes per image

type for the actual testing).

Interpreter Assignments (using 40 students who currently were taking photo interpretation courses at the University of California; see Appendix C):

Group I (20)	Group II (20)
Subdivided into sections A,B,C,D	Subdivided into sections A,B,C,D

Four sections of five interpreters each were chosen in such a way as to include in each section a range from high to low ability as determined from University course progress.

Interpretation Sequence (same image sequence and test procedure duplicated for Groups I and II):

The image sequence was rotated so that each image was interpreted in a different sequence by each section of five interpreters, thus minimizing bias due to interpretation sequence.

May 16, 1974 - Color Images (5-8)

Section (5 Photo Interpreters Per Section)	Sequence in Which Images Were Interpreted			
	1	2	3	4
A	5	8	7	6
B	6	5	8	7
C	7	6	5	8
D	8	7	6	5

May 23, 1974 - Black-and-White Images (1-4)

Section	Sequence in Which Images Were Interpreted			
	1	2	3	4
A	1	4	3	2
B	2	1	4	3
C	3	2	1	4
D	4	3	2	1

Photo Interpretation Responses (sample response sheet, Figure B1):

(10 responses/crop category) x (6 crop categories/image) x (8 images/PI) = 480 responses/PI

Each test image was accompanied by a clear acetate overlay containing an annotated sequence of training and test items. With the overlay positioned correctly, each labelled dot fell well within a uniform image area belonging to one of the test categories. The interpreters were asked to make judgments regarding the identity of the image area within the vicinity of each dot.

Instructions were standardized so that each interpreter would proceed in the same manner during the entire testing period. During the training phase, interpreters were instructed to study the image characteristics of each category. Two examples of each category (which were judged to be representative of that category within the test region) were provided for this purpose. The interpreters were asked to establish for themselves the image attributes (color or tone, texture, pattern, shape, topographic position, etc.) which

PI RESPONSE SHEET
ERTS SKYLAB AGRICULTURAL PI TEST

NAME:________________ IMAGE:______
GROUP:______ SECTION:____________

IMAGE #	RESPONSE	IMAGE #	RESPONSE	IMAGE #	RESPONSE
1		21		41	
2		22		42	
3		23		43	
4		24		44	
5		25		45	
6		26		46	
7		27		47	
8		28		48	
9		29		49	
10		30		50	
11		31		51	
12		32		52	
13		33		53	
14		34		54	
15		35		55	
16		36		56	
17		37		57	
18		38		58	
19		39		59	
20		40		60	

KEY TO TEST RESPONSES:

R - rice	F - fallow
O - orchard	G - dryland pasture
A - alfalfa	X - other agricultural crops

Figure B1. Sample interpretation test response sheet

characterized each category. No interpretation key or other descriptive material was provided. Each interpreter, working independently, established his own criteria for identifying the test items.

The testing phase was accomplished using a uniform time interval of 30 seconds for each test item (30 minutes for each test image of 60 test items).1/ For a particular set (e.g., the eight image types comprising Test 1), the sequence of image types was rotated as previously described. The interpreters were asked to study each test item on a given image type, compare it to the training examples, and decide which of the categories it most closely resembled. The letter code of the category selected for that test item was then to be recorded on the response sheet (Figure B1).

2.1.2 ADDITIONAL BACKGROUND PROVIDED TO INTERPRETERS FOR NATURAL VEGETATION TESTS

The ecological knowledge and understanding of the photo interpreter is a strong determinant of both the accuracy and information content of his interpretations of natural vegetation ecosystems. In an operational context, each interpreter must know what to expect on the landscape being interpreted. This means that he must use prior field experience in the project area to understand the kinds of vegetation which occur, the interrelationship of the vegetation types one to another, and their relationship to the topographic and soil environment. To the extent

1/ The instructor in charge also served as a "timer" by orally stating (after 25 of the 30 seconds had elapsed for interpreting a given test item) "5 seconds left" and then announcing the number of the next test item at the end of each 30 second period. The students used in these tests reacted favorably to this procedure.

that this knowledge grows, his interpretation ability increases. For an image comparison test, variable knowledge among interpreters regarding the area and its ecology may introduce additional and undesirable variability into the test. Ideally, as a test of the imagery alone, it would be best if all interpreters were at the same knowledge level. Thus, the test results should reflect differences in image characteristics, not differences in interpreter ability.

In this test, photo interpreters were used who, as a group, knew little about the plant ecology of the Colorado Plateau Test Region. A brief illustrated lecture on vegetation types and ecological zonation in the area of the Test Region was presented so that all interpreters would begin at the same level of understanding. The background material was presented without reference to the specific test area or to the ERTS or EREP image signatures of the various classes to be interpreted. The natural vegetation categories discussed are listed in Table B2. The lecture included presentation of the complete zonation of these categories from the saltdesert, shadscale types typical of the deeper, drier valleys through the sagebrush, juniper, ponderosa pine, and spruce-fir zones.

In the above presentation, specific ERTS or Skylab image characteristics associated with each vegetation type were not mentioned. It was left entirely to the individual interpreters as they studied and analyzed the two training examples of each test category to develop the image-subject relationship criteria they would individually use in the interpretation tests.

Appendix C

GUIDELINES FOR MAPPING EXPERIMENTS

1.0 DELINEATION GUIDELINES

The imagery will be delineated by considering vegetation, land uses that have changed the earth surface feature, barren land, water resources, macrorelief, and landform. A specific numerical legend is provided for each of these categories. Study the legend classes before you start actual delineation to become familiar with the criteria for delineation.

When you are ready to begin delineation, fill out the top of the record form, paying particular attention to the time of starting, time of ending, and a best estimate of lost time through interruption during the working period. Try to do the work in a period when you can eliminate interruption.

1.1 PURE DELINEATIONS

1. Map pure delineations whenever possible. Map pure delineations first and work to more complex examples.

2. First delineate the most contrasting subjects and work to the less and less contrasty until a further subdivision of the landscape is no longer practical and meaningful.

3. Map strongly contrasting, highly important features (such as highly productive types and urban or agricultural areas) to a minimum area of 1/2 sq. cm. $\square$*

*The "minimum area" specified represents the smallest area as seen on the imagery, which, if found to exhibit a unique appearance, will be seperately delineated. Many delineated areas, however, will be much larger than the minimum because they are essentially homogeneous despite their larger size.

4. Map contrasting, moderately important features to a minimum of 1 sq. cm. *

5. Allow inclusions (i.e., small areas that do not match their homogeneous surroundings) that are ignored in symbolization up to an aggregate of 10% of the delineation area as long as they do not fit condition 2 or 3. Avoid "lumping" for reasons shown in the accompanying example. Table C1.

6. If the macrorelief-landform changes but the vegetation does not, make separate delineations with a common numerator, and vice versa.

1.2 COMPLEXES

1. Delineate the obvious and simplest complexes first, work toward more complex.

2. When mapping complexes, never map more than 3 characteristics or earth surface features in the same delineation--strive generally for two, and remember that a significant change in the proportion of any one characteristic or earth surface feature can necessitate separate delineation of the area in which it is found, provided that it exceeds the "minimim area" standard.

*The "minimum area" specified represents the smallest area as seen on the imagery, which, if found to exhibit a unique appearance, will be separately delineated. Many delineated areas, however, will be much larger than the minimum because they are essentially homogeneous despite their large size.

3. Inclusions aggregating less than 10% of the area should be ignored.

2.0 IDENTIFICATION GUIDELINES

1. Enter identification symbol(s) by number.

   a. Push identification as far toward refined classes as you can, to the point that you consider the odds favor the probability of a correct decision, i.e., >50 percent.

   b. If you can't make an identification or distinction at one hierarchical level, back up the most refined level that does permit you to meet condition 1.a.

2. Do not symbolize inclusions.

3. In identification of complexes, enter symbols of components or features in decreasing order of areal extent within the delineation.

4. Symbolize both numerator and denominator as follows:

$$\frac{\text{SURFACE FEATURE}}{\text{LANDFORM}}$$

Table Cl. Mapping Experiment, Natural Vegetation

Name of P.I.:____________________

Date:____________________

TIME START:________ TIME STOP:________ LOST TIME:________

Delin. No.	In Image Quad.	Boundary Rating	Ident. Rating	IDENTIFICATION						Propor-tion of Area
				Symbol	%*	Symbol	%	Symbol	%	

*If pure type leave blank; if complex enter in 10% classes 2, 3,...8 (remember a 10% class is ignored as an inclusion).

Appendix D

PHOTO INTERPRETATION RESPONSE FORM FOR YIELD ESTIMATION

This form is used to tabulate responses of photo interpreters for each photo date and film record obtained. At the end of the season actual yield supplied by the cooperating farmers is compared with estimated yield to arrive at error figures.

Sheet No.____

PHOTO INTERPRETATION DATA
YIELD ESTIMATES

Interpreter________________

PHOTO DATA

Area____

Photo Date________________ Scale________________

Film/Filter________________ Photo Quality________________

PI DATA

Field No.									
Field Acreage, Actual									
Field Acreage, PI									
Potential Yield, tons/acre									
Field Potential, %									
Field Potential, tons/acre									
Yield % Reduction Factors, Total Effect	Disease								
	Lodging								
	Soil								
	Other								
Total Yield Reduction, %									
Net Yield, tons/acre									
Actual Yield, tons/acre									
Error in Estimate, tons/acre									
Error in Estimate, % ±									

(Use other side for calculations.)

Appendix E

CHART OF COMMISSION AND OMISSION ERRORS

FOR AGRICULTURAL TESTING

AGRICULTURE TEST RESULTS

Name SUMMARY

Group I and II

Image Type 1 (S-190B color

Ground Truth

PI Calls

	R	S	P	F	Error Total	% Comm.
R	68	0	4	0	4	6
S	0	43	27	0	27	39
P	2	27	39	0	29	43
F	0	0	0	70	0	0
Error Total	2	27	31	0	60/280	
% Comm.	3	39	44	0		21% Error
Total	70	70	70	70		

AGRICULTURE TEST RESULTS

Name SUMMARY

Group I and II

Image Type 2 (S-190A color)

Ground Truth

PI Calls

	R	S	P	F	Error Total	% Comm.
R	67	1	3	0	4	6
S	0	41	15	0	15	27
P	3	28	51	0	31	38
F	0	0	0	70	0	0
Error Total	3	29	19	0	51/280	
% Comm.	4	41	27	0		18% Error
Total	70	70	70	70		

AGRICULTURE TEST RESULTS

Name SUMMARY

Group I and II

Image Type 3 (S-192 color composite, Louisiana)

Ground Truth

PI Calls

	R	S	P	F	Error Total	% Comm.
R	61	3	1	0	4	6
S	1	49	12	0	13	21
P	8	9	57	0	17	23
F	0	9	0	70	9	11
Error Total	9	21	13	0	43/280	
% Comm.	13	30	19	0		15% Error
Total	70	70	70	70		

AGRICULTURE TEST RESULTS

Name SUMMARY

Group-Section I and II

Image 4 and 5 (S-192 color composite, California)

Ground Truth

PI Calls

	R	0	A	F	G	X	Comm. Error	% Comm.
R	52	7	26	0	2	21	56	52
0	1	66	1	0	3	3	8	11
A	24	2	58	0	0	11	37	39
F	2	17	0	72	7	11	37	34
G	4	4	1	27	77	0	36	32
X	17	4	14	1	11	54	47	47
Omm. Error	48	34	42	28	23	46	221/600	
% Error	48	34	42	28	23	46		37% Error
Total	100	100	100	100	100	100		